PRACTICAL ELECTRICITY

—Wide World Photos, Inc.

THE CITY LIGHTS HER LAMPS AT NIGHT

Evening shadows and starless nights no longer alarm the city dweller or the traveler. The highways and byways are well lighted by electricity. Railroad traffic circles, great bridges, wide streets, tall buildings, theater lobbies, all are bejeweled with a million lamps turned on each night.

Night is no longer dark when the electron is called into service.

PRACTICAL ELECTRICITY

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PREFACE

EVERYWHERE electricity is rapidly gaining in its manifold uses. The tiny yet mighty electron is forced to be a willing servant to mankind in all walks of life. From electrified ocean liners and rolling mills, to automatic telephones and television, uncounted hundreds of new uses of electricity unfold themselves in swift succession. Future uses seem to be practically unlimited.

To the student, the science of electricity proves to be increasingly fascinating, with study. The wide field of interesting experimentation opened by this force has greater possibilities for invention and application than almost any other field of endeavor. It provides not only a worthy hobby but also a sound vocation. No other field has risen so mightily in so few years of history, or has so brilliant a future.

This book aims to set forth the principles of the science of electricity in as clear a manner as possible. It is a text designed to be practical, yet theoretical enough to furnish a reasonable background for the practice. It is intended as an elementary text in the subject, to be used by students in vocational and industrial schools, mainly, who have not studied electricity previously and whose mathematical training may not have gone beyond arithmetic. The book is as inclusive of the general field as is consistent in a first course. However, it should not be mistaken as a complete condensed treatise on the entire subject. It is strictly a first course on the principles, and should be followed by more detailed courses in machines and systems.

All the features of the book have grown out of the author's experience in various branches of professional engineering and as a teacher of the theory of electricity in a technical high school. The problems represent the practical side of the science, and are intended to provide reality as well as opportunity for application of the principles studied.

JOHN EDMUND CRAWFORD

Pittsburgh, Pa.
January, 1939

SUGGESTIONS TO THE STUDENT

1. **Develop Your Own Experience Through Experiment.** The science of electricity, which you are just beginning to study, has for many years interested and fascinated many people. It is such a wide and increasingly interesting science that the more you study it, or experiment in it with wire, batteries, and magnets, the more it will engage your talent. You will, no doubt, find in electricity the most interesting hobby and work you have yet discovered in school.

Do not be afraid to test any of the ideas set down in this book. You must learn clearly to do your own thinking, so far as possible. You are not asked to believe anything you cannot prove or find proven somewhere. All statements made rest on sound proof that may be checked with relatively simple methods and apparatus.

As opportunity presents itself, obtain your own experimental equipment and try out for yourself these fundamental ideas. For example, find out by your own experiment whether or not "unlike magnetic poles attract." In your own way prove to yourself that a coil carrying an electric current has magnetic flux set up around it. The sense of achievement you will gain from doing some experimenting yourself, with your own materials, will be worth much to you. You will learn many things about the tiny electron and its peculiar characteristics under certain circumstances, from this kind of work.

2. **Keep a Neat Notebook of Your Data.** In this course, you will gather many very useful formulas, and arrive at many interesting conclusions. These will all be valuable to you later in other advanced courses in the science of electricity. Keep neatly written and diagramed notes, in brief form, of these ideas and facts, by some catalogue method.

For example, it is convenient to divide your entire electricity notebook into chapters corresponding to those in this book. Each

of these notebook chapters may be nicely headed by a book plate or a design that will illustrate or introduce the chapter. Watch for pictures in magazines and newspapers that may be used or copied as part of your chapter-page designs.

You might also subdivide each chapter into such units as definitions of new electrical terms, new formulas, diagrams, pictures of machines, or electrical parts, and any other miscellaneous data that may develop. Such a catalogued notebook will make review and study of the subject very easy. It will also provide an excellent "condensed text" that may be used as a reference in your advanced electricity course next year.

Keep especially clear notes, with sketches and wiring diagrams, of any of your experiments. Make a record of your findings, with any remarks you may have about their probable "error" or how the experiments could be improved. A good deal of joy can be had in a well-kept notebook that has about it the mark of your own thought and individuality.

3. **Problems, Tests, and Answers.** Every student knows that by doing many problems on a given unit of learning, he will become expert at the work. The best way to learn a principle, or a fact, is to use the idea in several increasingly difficult problems. In working out the intricate parts of a problem, the student gets a better understanding and insight into these details and how they fit together.

Too often we merely fumble through our problems, instead of using some kind of plan. Before any attempt is made at the figures in a problem solution, we must always think out our plan of solution and the reasons for the choices made of various formulas and facts used. Following are a few simple hints in problem solving, for this course, that will prove helpful to you:

1. Read the problem carefully. Decide what is wanted.
2. Draw a suitable diagram, whenever possible.
3. Show all given data on this diagram.
4. Solve the problem only after thinking it over.
5. Check the answer. Compare it to the given answer.
6. Interpret the answer in terms of "common sense."

This last point is perhaps the most important of all. Having arrived at an answer, check it first for accuracy, but do not

forget to check it also for its good sense, in terms of what you already know. For example, suppose the problem wants you to find out the number of amperes flowing through a No. 18 copper wire. If you get 6000 amperes for an answer, your common-sense check of this should indicate an error, because No. 18 can carry only about 5 amperes. Never fail to examine an answer, to check its reasonableness.

When a test is given, in this course, do it in a sincere effort to find out for yourself what *you* can do. There are, of course, many ways to cheat on a test, that are not always caught by the teacher. But after all, the fellow who cheats does not hurt anyone but himself; he becomes a shirker instead of a worker.

Tests are given to help you measure your own abilities. The test, properly designed and given, will prove a worthy challenge to your ability and to your intellect. Always do a good job on a test. Do your best. Then the score you make, compared to the scores of all the rest of your group, will give you a fair idea of how well you have mastered the necessary facts and principles. Learn to judge your own work; do not put false values on your work, but judge it honestly, in the light of what you could do if you were at your best. This is a competitive world, you know; you must learn to accurately compare your work with that of your fellow workman.

Answers to the problems are given at the end of the book. Check your answers against these after you have worked a problem as you think it should be done. Do not guess at the method of solution just to "juggle" the given data until you produce an "answer."

The purpose of answers is to give you a safe check on your work. When you arrive at the answer given for a particular problem, you can be rather certain that your method was also correct. If your answer is nearly the one given — say only 1 or 2 per cent off — this may mean that your method is correct but your calculations are somewhat inaccurate.

Always aim for accuracy, but be practical about it. There is little use in working one value to five decimal places, for example, when another value you intend to use in the same problem is only a guessed value or an estimated value. So, be accurate, but be reasonable about your figures. The answers given are as accurate as necessary for the problems considered in this text.

Use decimals; avoid fractions. We can all read and learn to use decimals easier than we can fractions.

4. Outline Your Reading for Easy Study. As you read this book, make a clear outline of the articles. In this way you will soon learn to pick out rapidly the main "threads" of thought. Keep these daily outlines in one section of your notebook, if you wish, as a brief of the text. Mark them with article numbers the same as the book numbering. This will tie the outline and text closely together, and make it easy to refer from one to the other.

Make your outlines in a manner that they will be easy to read and logical. Save words, but be sure to use enough to have clarity of meaning. Use a formula, wherever possible, to express facts and relations. Do not merely copy from the text. Use your own wording. Express things your own way.

5. Read This Book for the Pleasure of It. Do not try to memorize lengthy sections of this book. That is a waste of time. You will get more pleasure and inspiration to work and experiment and invent in the field of electricity, if you read ahead of your assignments. You can thus have the same kind of reaction you do when you run ahead of your group and from a higher point on the road watch them climb up to you. Besides, this reading ahead of where you are actually studying gives you an idea of just what the studied articles are "hitting at," as we say. Then daily explanations and problems will have the additional light of your advanced ideas thrown upon them.

All These Suggestions have been made merely as hints on how to do this job in the easiest way. The best way is always the easiest, in the long run. If you can make your study of the science of electricity an experience that you really like and want to have, then it will be easy to learn.

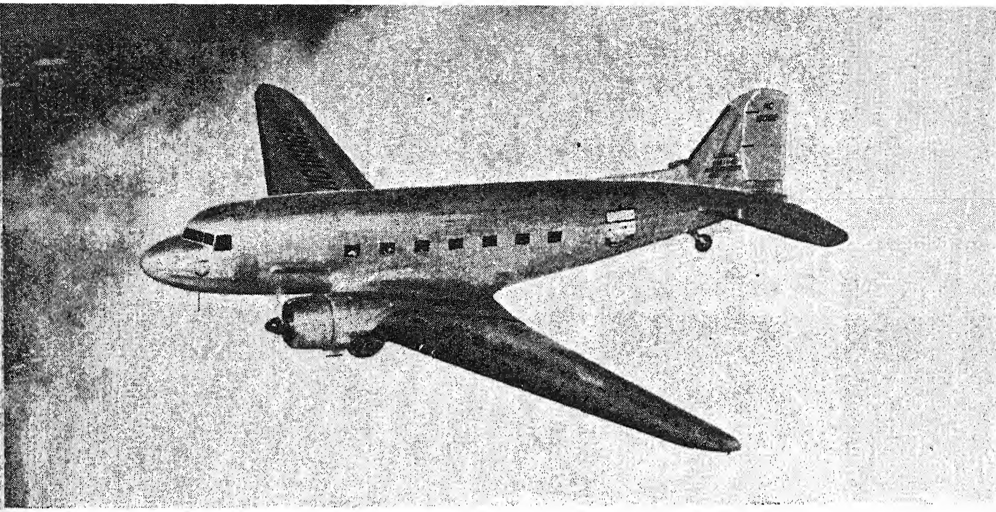
There are only a few laws in electricity, which govern all its many cases of application. Ohm's law and Watt's law are two of these, and are very simple to learn to use. You will find about six main "learning threads" or laws running through this science, like cords woven into a tapestry or rug, showing here and there, but always the same thread. Look for these main ideas, repeated in slightly different ways. The whole subject will become as simple and easy, yet as interesting and fascinating as anything you have ever done.

You have chosen to study and experiment with the most interesting science in all this vast world of sciences. Electricity will never be old or dull or drab to you. Every day it has a hundred new possibilities to make this earth of ours a better place in which to live.

J. E. C.

CONTENTS

EXPERIMENTS



— United Air Lines

THE ELECTRON GUIDES AND SPEEDS THE PLANE

The distant roar of motors grows rapidly fainter, as the great metal-winged transport moves swiftly and serenely across the sky. The passengers within read comfortably, unaware of rain and fog below, that blot out the tiny map of earth.

But the pilot is not worried. He flies the plane steadily along a radio-beaconed sky lane. He is constantly in touch, by radio telephone, with officers at near and distant airports, who tell him of heading weather and landing conditions. The passenger may talk with his home folk, if necessary.

Mighty engines, whose pulse beat is governed from sturdy magnetos and perfect ignition systems, drive the whirling propellers, cutting miles down into minutes, making New York almost neighbor to San Francisco.

Without the spark coil and its companion, the ignition system, such engines and planes would hardly have been possible.

Chapter I

CIRCUITS: HIGHWAYS FOR ELECTRONS

ELECTRICITY, as a real science, has been used by man as a great power for only about forty years to turn mills, lift elevators, and carry messages. Even at the present time, in many small towns oil lamps still smokily flicker on living-room tables during winter evenings. But some day, not too far in the future, electric power will be available to these little towns as easily as it is to large cities. And the same kind of tiny, rushing, energetic electrons that turn the great motors in modern ocean liners will flow smoothly through wires to light electric lamps in distant villages and isolated farm homes.

It all seems so marvelous and fascinating — this story of the electron — that it is difficult to know just where to begin to relate it. But because it will be so much easier to have some definite terms and commonly accepted facts as a basis for the other chapters in this book, some fundamental ideas about electricity must be set down here. Certain terms, like "ampere," "voltage," and "Ohm's Law" are used by all electricians or men engaged in any electrical work, as part of the correct vocabulary of the science.

1. **Electrons and Conductors.** Electricity really is made up of very small particles, called **electrons.** These are so very small that even the most powerful microscope would not make them visible to the eye. But when enough of these tiny electrons move in a stream, a current of dangerous size may result. This stream is quite comparable to a river, made up of very small particles of water. Although each speck may be invisible, yet the whole stream can be very powerful, depending on the number of particles flowing and also on how fast they flow. Any swimmer knows the truth of this.

One way to think of a current or stream of electrons flowing

through a seemingly solid wire or conductor is to compare it with a rubber hose filled with shot. If the shot, which compares to the particles of copper in a wire, is not packed in the hose too tightly, water will be able to squeeze through between the balls. The more pressure the water has behind it, the more water will be forced through the shot-filled hose. These shot balls are much like the metal grains, or molecules, in the wire. The rubber hose is like the insulation on the wire which keeps the flowing stream from getting lost. The water is like the electrons flowing through the molecules of the conductor. The pressure forcing the water through the shot is like the pressure forcing the electrons through the wire.

This water comparison will be used to explain and illustrate other facts about electricity to come later. For the present, keep in mind the thought of a current of electrons flowing in a conductor or wire. More about conductors as related to insulators can be found in Article 5.

2. The Ampere, Unit of Current. When water flows in our shot-filled hose, gallons per second may be used as a unit of measure of the flow. This unit, gallons per second, is the rate of flow of the water. In the same manner, an electric current of electrons in a wire may be measured in certain units. Electrons are so tiny, and so invisible, that such a unit as electrons per second would be very difficult to use.

A noted scientist, Chas. A. de Coulomb, years ago decided to make a larger unit of flow the standard. He used what he termed coulombs per second, a single coulomb being about 6,300,000,000,000,000,000 electrons.

To further simplify matters, another scientist, named André Ampère, later decided to call a coulomb per second of flow an ampere. Thus, when the current is 1 ampere, it means that 1 coulomb of electrons passes a point in the wire in 1 second, or

1 ampere = 1 coulomb per second, or
1 ampere = 6,300,000,000,000,000,000 electrons per second, past a given point.

The important thing to remember here is that the term ampere simply means the rate of flow of the electricity, in terms of a certain number of electrons per second.

2 amperes = twice as rapid a flow as 1 ampere.
4 amperes = 4 times as many electrons per second as 1 ampere represents.

3. The Volt, Unit of Pressure. Referring to Article 1, you will remember that the pressure on the water in the shot-filled hose affected the flow of the water. The more pressure applied, the faster the water will flow. The less pressure, the slower the flow, or the less the flow. That is just common sense.

The same rule is true in electricity. The pressure behind the electrons affects their rate of flow, or the amperes. This pressure is called either **voltage** or **electromotive force,** which mean merely the electric pressure applied to the electrons to make them flow in a stream. The **volt** is simply the common unit of measure of this pressure or force. The name comes from the name of one of the early electrical experimenters, Alessandro Volta. These pioneers in the sciences had to make up names for the new units they discovered, and frequently used their own or their friends' names for units.

It is only important to remember that by **volt** is meant a certain amount of electric pressure, or force, tending to cause any electrons present to flow in a current, or amperes. The amount of pressure, or the voltage, has much to do with the amount of amperage.

4 volts make 4 times the number of amperes that result from 1 volt.
10 volts produce 10 times the amperes obtained from 1-volt pressure.

4. The Ohm, Unit of Resistance. Resistance is easy to understand if you think of it as the "holding-back" quality of a material to the flow of current. For example, the shot-filled hose, of Article 1, will have more and more resistance to the water, the tighter the shot is packed in the hose. The smaller the holes in a material, the more resistance it is bound to have to the flow of any particles through it.

In the mechanical world, this holding-back quality of anything is usually called **friction.** In the electrical fields, this friction or holding-back characteristic is always called **resistance.** In honor of G. S. Ohm, the man who discovered a law that

exactly relates current, voltage, and resistance, described in Article 7, the unit of resistance in electricity was named the ohm.

5. Insulating Materials. Insulators are materials such as glass, hard rubber, and very dry or waxed papers which do not conduct current. In other words, their resistances are very great, say, several million ohms. This means that insulators are the exact opposite of conductors. What one does, the other must not do. Metals always have spaces large enough for electrons to pass through, and some free electrons to make up the current. You could hardly wring water out of a dry cloth, or even a very slightly damp rag. There must be some "free" water, or electrons, in a material, in order to have a current, regardless of the pressure applied.

Insulators are different. In any insulating material, all the electrons are so securely attached to the particles of the insulator, called "atoms," that it is nearly impossible to break them away and make them flow. It is the nature of some materials, such as glass, to be insulators, while others, such as copper, are conductors.

There are many grades of insulators, ranging from very good to very poor. Very poor insulators are merely high-resistance conductors, as shown in Table I. You probably know of the various materials listed and their uses.

Reading the table, you will note that the materials listed just above and below 10 are of no practical value as good insulators or as good conductors. The reason that lead is used for the terminals on storage batteries is because of certain battery characteristics that will be discussed in another chapter. Of course, silver would be a very fine material from which to make electric cables, but it would obviously cost far too much to be used economically. Aluminum has a little higher resistance than copper, but is very light weight and reasonably cheap. It is rapidly coming into common use for transmission lines.

6. Meters. Many kinds and types of meters are in electrical use. The common ones are the ammeter, voltmeter, wattmeter, ohmmeter, and watt-hour meter. The name of a meter gives an idea of its use. The ammeter is used to measure current in amperes, the voltmeter to measure electromotive force in volts, and so on.

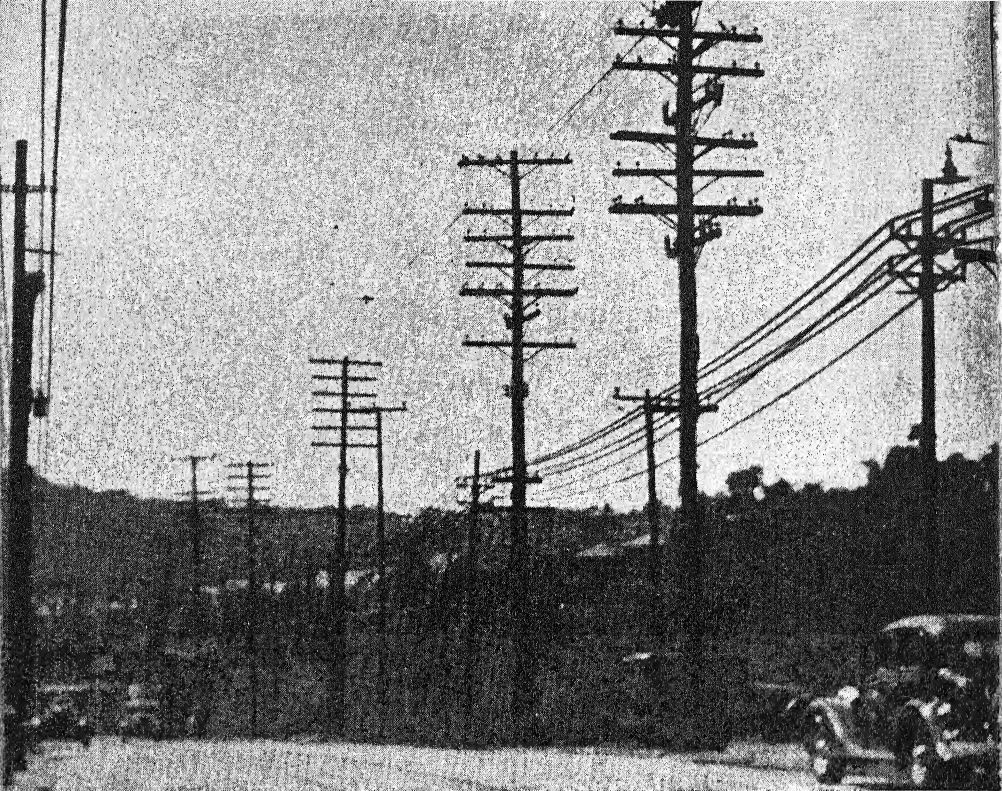
TABLE I. RELATIVE ORDER OF MATERIALS

	Material	*Value as Insulator*	*Value as Conductor*
1	Fused quartz	extremely good	of no use
2	Glass, porcelain	very good	of no use
3	Mica	very good	of no use
4	Rubber	very good	of no use
5	Waxed paper	good	of no use
6	Varnished cambric	good	of no use
7	Bakelite	fair	of no use
8	Asbestos board	poor	of no use
9	Dry wood	very poor	of no use
10	Damp wood	extremely poor	extremely poor
9	Nichrome	of no use	very poor
8	Lead	of no use	poor
7	Steel rails	of no use	fair
6	Iron (soft drawn)	of no use	good
5	Brass	of no use	good
4	Zinc	of no use	very good
3	Aluminum	of no use	very good
2	Silver, pure	of no use	very good
1	Copper	of no use	extremely good

Meters come in several common styles. One is the panel type, as used on automobile dash panels. The handy pocket type, sometimes called "watch-case" type, also is familiar as a battery tester. This meter usually has two scales and two windings, one for current, and one for voltage. But regardless of what kind of box or case a meter is enclosed in, the operating principle of an ammeter, or a voltmeter, or any other kind, is always the same for that particular kind.

In Chapter VI, details for constructing a simple ammeter and a voltmeter are given. Cheap dollar meters can be used nicely for the ordinary electrical experimenter's work at home. When buying meters, be careful to get those with the needed range of readings for the intended purposes.

Great care must be taken in connecting meters of any kind to any circuit. Damage to the instruments, and in many cases serious injury to the electrician doing the job, may result from wrong meter connections. The better commercial meters are of the jeweled bearing type, with accurately made parts. Such instruments are expensive. The average house-type watt-hour meter, with a glass case enclosing the working parts, costs about



HIGHWAYS FOR ELECTRONS

Millions of miles of wires stretch over city and over countryside alike, as paths for a mighty power of electricity. The earth has yielded her tallest trees and finest copper to the service of the world of electric power, light, and communication.

The finest insulation is put to work to keep every electron possible within the bounds of its prescribed circuit of copper.

The lineman, with his expert workmanship, is largely responsible for the excellent maintenance and operation of these lines.

thirty-five dollars. This gives an idea of why power companies keep close records of their metering instruments, and are careful to inspect meters at least once a year for defects.

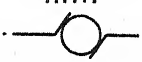
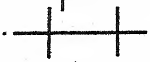
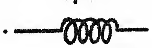
So it seems worth while right here to show how to correctly connect meters. But, first, some of the more common diagram symbols must be shown, as a better basis for understanding the metering diagrams later.

7. Diagrams and Symbols. Diagrams are to the electrician what the road map is to the tourist, or what plans are to the contractor building a house. Road maps do not contain pictures of the roads, but merely diagrams of them, in a clear, understandable fashion. Likewise, electrical diagrams of house-lighting circuits, of motors, or any other circuits, do not contain pictures of the parts used, but merely certain standard symbols that are commonly used to represent the parts.

For example, only the electrical circuits are shown. No rubber insulation, motor frame, lamp stand, or other mechanical details are shown. If two wires cross, without any contact, they are represented by two lines crossing. Joined wires are indicated in a diagram with a small round dot on the "joint."

Coils are not diagramed with the exact number of turns on the

TABLE II. DIAGRAM SYMBOLS

Battery, any kind	
Generator or motor	
Resistance, fixed	
Resistance, variable or rheostat	
Ammeter	
Voltmeter	
Switch	
Joint between wires	
Crossover, no joint	
Ground to earth or to frame	
Coil or electromagnet	

real coils, but merely as a few neatly drawn loops, to give the idea of a coil.

Parts are placed in a diagram to make the complete diagram easy to read. Examine Table II of the part symbols commonly used. Make up your own symbol for any new part you want to show that is not included in Table II.

Examine Figure 1 as a sample diagram; note its clear form, its straight, neat lines. Switches (such as snap, push, key, etc.) are always shown with the contacts in the open position, for clear detail of the diagram.

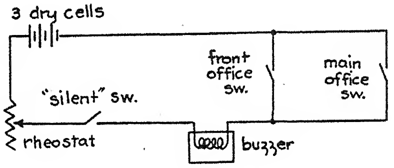


FIG. 1. Diagram of simple office call system.

It is well to mention here some of the commonly accepted abbreviations used in the following chapters and in other electrical handbooks. These abbreviations save much lettering on diagrams, and their use makes a neater drawing.

TABLE III. ELECTRICAL ABBREVIATIONS

Current, in amperes	amps.; A; (in Ohm's law, I)
Voltage, in volts	volts; V; (in Ohm's law, E)
Resistance, in ohms	ohms; Ω ; (in Ohm's law, R)
Power, in watts	watts; W; (in Watt's law, W)
Power, in horsepower	h.p.
Speed of machines	r.p.m. (revolutions per minute)
Speed of machines	r.p.s. (revolutions per second)
Direct current	d.c.
Alternating current	a.c.

There is no need to memorize all these symbols and abbreviations. You will very soon learn them from use in your electrical work. But it is interesting to know where the three letters, *I, E,* and *R,* used in Ohm's law to represent current voltage, and resistance, came from. These three letters, as used

in this law, and the *W* as used in Watt's law are the agreed international standard.

I, for current, stands for............ **Intensity of the flow.**
E, for voltage .... **Electromotive Force** or pressure of the flow.
R, for resistance.................... **Resistance.**
W, for power .... **Watts of power.**

Now, to return to the trend of thought left off in Article 6, something should be shown about proper connections for meters.

8. Ammeter Connections. Regardless of the type of ammeter used on any circuit, its purpose is always the same. That purpose is to measure the amount of amperes, or coulombs per second, flowing in the circuit.

In some respects, an ammeter is similar to a water meter or a gas meter. They are all connected in the pipe line or wire circuit. Whatever flows through the pipe or wire also must pass through the meter to be counted or measured. So, if an ammeter is to measure the electric current through a lamp, the meter must be connected as shown in Figure 2. All the current of the lamp also must flow through the meter.

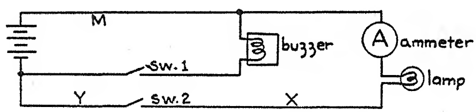


FIG. 2. Ammeter connected to indicate lamp current.

This ammeter also may be correctly connected in the line at *X* or at *Y*, where it will read the same as at the place it is shown. At *A*, *X*, or *Y*, it will indicate the lamp current in amperes.

But if the ammeter is placed at *M*, it will measure either the lamp current or the buzzer current, or both, according to the manner in which the two switches are operated. This *M* location allows one ammeter to serve two purposes without any wiring changes. With careful planning, including neatly drawn diagrams that have been "traced out" for current paths, such economies in equipment are often possible.

In choosing an ammeter for a job, always make sure to use

one that has a high enough scale. For example, suppose an electrician does not know exactly how much current is flowing in a wire, but he has estimated it to be about 50 amperes. He should use a meter with about a 200-ampere-scale limit, to take care of any error in the estimate. If this meter shows only 35 amperes, then, but not until then, he may substitute a lower scale meter, say 50 amperes in this particular case.

If he had used the 50-ampere-scale meter first, and the estimated current had actually been 65 amperes, then the 50-ampere meter would have been ruined.

Ammeters made for direct-current circuit are not suitable on alternating-current circuits. They will not read correctly unless used on the proper circuit, d.c. or a.c., as stated on the meter faceplate.

9. Voltmeter Connections. All voltmeters are instruments used to measure electrical pressure, or electromotive force, sometimes abbreviated e.m.f. This e.m.f. is measured in units of **volts**, as steam pressure in a boiler is measured on a steam gauge in pounds.

A voltmeter is always connected across the line or apparatus whose voltage is to be measured. In Figure 3, a method is diagramed for reducing the line voltage applied to a small motor by an adjustable rheostat, R. The voltmeter, V_1, is used to show the voltage actually applied at the motor terminals.

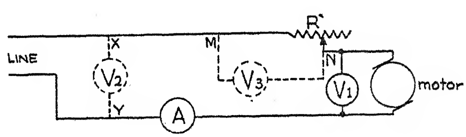


FIG. 3. Voltmeter connected to show voltage at motor.

If this meter reads 10 volts, it means that in passing through the motor the current drops 10 volts in pressure. Under Ohm's law, more will be said about this "voltage drop," and what causes it, although you have probably guessed rightly that it is caused by the resistance of the motor windings. You know that a bullet, when passing through a tree, rapidly loses its force. Likewise, electrons (or current) in going through a wire having any resistance at all, rapidly lose their e.m.f. or voltage. The voltmeter in the diagram indicates this "drop" in voltage.

If connected across the main line at *X* and *Y*, the meter would read the main-line voltage. Or, when connected across the rheostat at *M* and *N*, the instrument would indicate the "voltage drop" across the part of the rheostat being used.

As with ammeters, no d.c. voltmeter will work correctly on an a.c. circuit, nor will an a.c. meter read right on a d.c. line. Therefore, always notice the "faceplate" for the a.c. or d.c. marking. Also, always be careful to use a large enough scale meter to cover any possible error in estimating or guessing the probable voltage. It is better to use a meter that has so high a scale that the needle moves only a little bit when the meter is connected to the line, than to use a low-reading meter and suddenly see its needle wrap around the end pin or stop when the meter is connected. A little forethought when using valuable equipment is always better than a lot of "afterthought."

10. Ohm's Law. From the comparison in Article 1, of a wire carrying an electric current to a shot-filled hose carrying a water current, several generalities can be stated here.

1. A generator or battery is like a water pump. Both supply the necessary pressure to make the electricity or the water flow through the conductor.
2. Water always flows from a high level to a low level, or from a high pressure to a low pressure. Likewise, electricity always flows from a high voltage to a low voltage or pressure.
3. The greater voltage or pressure, the greater the current. The less the voltage, the less the current.
4. The more resistance, the less the current. The less resistance, the greater the current.

These four points are always true of all electric currents.

There is a way to find the number of amperes in a circuit when the voltage and resistance are known,

or

—how many volts pressure is needed to push a certain current through a known resistance,

or

—how many ohms resistance will keep the current down to a certain amperage, in a circuit of known voltage.

These three units of

current (amperes), represented by I,
voltage (volts), represented by E, and
resistance (ohms), represented by R,

are related by Ohm's law. Georg Simon Ohm discovered that voltage and current, in any particular circuit, are always definitely related. For example, he discovered that when an ammeter and a voltmeter are connected in a circuit, as shown in Figure 4, any change in the ammeter reading is accompanied by a change in the voltmeter reading. In other words, he found that when the voltage changes, the current also changes.

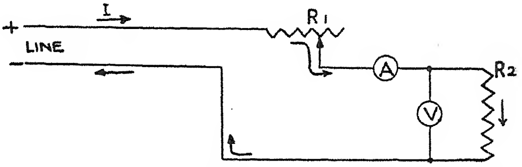


FIG. 4. The ammeter-voltmeter resistance method.

The rheostat, R_1, can be adjusted to allow more or less of the line voltage to be applied to the R_2 resistor under test. If you connect up this circuit, you can readily check Ohm's conclusions. Make about four rheostat adjustments, and record the meter readings for each one. Your data may be tabulated as in Table IV. Your values may not be the same as these, depending on the battery voltage and on the resistor values, but the general idea will be the same, and from your own figures you may check the law. For the present, accept Table IV as technically correct data for a possible case:

TABLE IV. AMMETER-VOLTMETER DATA

R_1 *Rheostat Setting*	*Amperes Through* R_2	*Volts Across* R_2
a	1	4
b	2	8
c	3	12
d	4	16

Examine Table IV. Try to discover a way to calculate the resistance of R_2 (4 ohms), by using the amperes and volts of

any reading. Notice that by dividing the voltage by the amperage the result is always the R_2 resistance of 4 ohms. This may be more clearly written in a formula, like this:

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}, \text{ or ohms} = \frac{\text{volts}}{\text{amperes}}.$$

Better still, this may be written in an algebraic form by using the letters E for voltage, I for current, and R for resistance. The foregoing formula now becomes

(1) $R = \dfrac{E}{I}$ (meaning, of course, that $R = E \div I$).

In the same way, by inspecting the data in Table IV, it may be seen that

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}, \text{ or amps.} = \frac{\text{volts}}{\text{ohms}}$$

(2) which in the simpler algebraic form is, $I = \dfrac{E}{R}$ (or $E \div R$).

Also, Voltage = Current × Resistance, or volts = amps. × ohms,

(3) written in algebraic form, $E = IR$.

(Note that the "times" sign does not need to be shown, but is always understood to be there. IR means I times R.)

Examples:

1. The voltage drop across an electric iron is known to be 110 volts. The iron "draws" 5 amperes from the line. What is the resistance of this iron? (To find: ohms or R.)

Ohm's law: $R = \dfrac{E}{I}$; ohms $= \dfrac{\text{volts}}{\text{amps.}}$.

Substituting, $R = \dfrac{110}{5} = 22$ ohms. Answer.

2. How much current will a 50-ohm lamp draw from a 100-volt line? (To find: amps. or I).

$$\text{Ohm's law:} \quad I = \frac{E}{R}.$$

$$\text{Substituting, } I = \frac{100}{50} = 2 \text{ amperes. Answer.}$$

3. What voltage is needed to force 6 amperes through a resistance coil of 10 ohms? (To find: volts or E.)

Ohm's law: $E = IR$ (the "times" sign is not needed).
Substituting, $E = 6 \times 10 = 60$ volts. Answer.

Suggestions: If the letter formula seems too vague at first, use the unit (or word) formula for a while. The main idea is to become familiar with the three forms of Ohm's law. It is the most useful law or rule in electricity. It is always correct, if correctly applied, and is easily applied.

A simple little device may be used to keep this law in mind. By writing the units or letters as shown in Figure 5, and covering up the desired unit of volts, amps., or ohms to be found, the two remaining letters will be in the correct formula to use. It is not necessary to always draw out such a scheme on paper. The memory of it will keep the law firmly in mind.

$$\frac{\text{(Volts)}}{\text{(Amps.)} \times \text{(Ohms)}} \qquad \frac{E}{I \times R}$$

FIG. 5. Ohm's law condensed.

Ohm's law applies to all direct-current (d.c.) circuits. It can also be applied to a.c. circuits when certain characteristics of an a.c. circuit are considered, which will be discussed in Chapter VIII. But if the apparatus does not contain large coils of wire, and has only plain resistance, then Ohm's law applies to it as shown in the preceding examples, regardless of the circuit being d.c. or a.c. Thus, in Example 1, about the iron, no mention was made about the circuit being a.c. or d.c. because it does not matter. Electric irons have very little if any coils in their resistance wires.

One caution, however, must be kept in mind when using Ohm's law in any circuit problem. **All three factors — amperes, volts, and ohms — must pertain to the same part of the circuit.**

If the line resistance is to be found, the line voltage and line current must be used.
If the current through a bell is to be found, the bell voltage and bell resistance must be used.
If the voltage on a motor is to be calculated, the motor current and motor resistance must be used.
In other words, all values must refer to the same part of the electrical circuit, otherwise, the result obtained will not be correct. This is very important to remember when applying Ohm's law to any special part of a circuit, or to the circuit as a whole.

The next few articles will discuss the application of Ohm's law to the two main types of circuits in common use. These are called "series circuits" and "parallel circuits."

11. Series Circuits. There are many practical examples of series circuits. Strings of the smaller variety of colored lights for Christmas decorations are usually connected in series. Arc lights for street and highway illumination are connected in series. In Figure 6, a typical series-lighting diagram is shown.

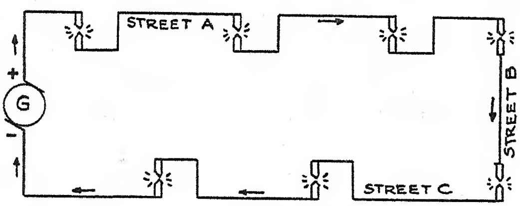


FIG. 6. Series arc lights for street lighting.

Figure 6 shows the general idea of series circuits. Whatever current flows through one part of this circuit (or any other series circuit), must pass through all the other series parts. This is because a series circuit has only one path for the current. In the diagram in Figure 6 it is shown that if 100 electrons leave the + side of the generator, the same 100 electrons finally must

return to the generator at the — terminal. In the meantime, these same 100 electrons passed through the series-connected arc lamps, one after another. Of course, all the parts and wires must be well insulated, to allow no electrons to flow along any other path than the desired one of the street lights.

Therefore, in any series circuit, the current (I) is the same throughout all parts of the circuit. This is a very important point.

Now, suppose each street light causes the electric pressure (e.m.f.) behind the current to lose 20 volts (IR drop). Then, in passing through the 7 arcs shown in the Figure 6 circuit, the total voltage lost would be 20×7, or 140 volts. Therefore, even if no further voltage drop occurred in the long wires on poles between lamps, generator G would have to supply at least 140 volts to keep the current flowing in the circuit. Less than 140 volts would cause the arcs to sputter or not light at all. More than 140 volts would burn the carbons too much and cause lamp failures. And if one part of a series circuit burns out, none of the other parts have current. What happens when one lamp in a series Christmas-tree "string" burns out? The same thing is true of all series circuits.

Therefore, in any series circuit, the total voltage or total voltage drop (E_{total} or E_t) always is equal to the sum of the voltage drops of all the parts of the circuit. This also is a very important point.

12. Ohm's Law in Series Circuits. In applying Ohm's law to any circuit, series or otherwise, it is necessary to keep in mind one caution. That is, always use the values of amperes, volts, and ohms that pertain to the particular part of the circuit to be considered. An example will make this quite clear.

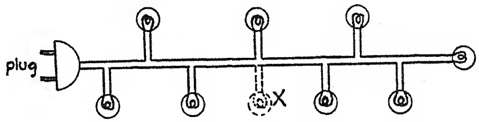


FIG. 7. Miniature lamps in series.

Ornamental or decorative strings of miniature lamps, such as for Christmas-tree use, are usually made up of 8 lamps, 12.5 volts each, connected in series as shown in Figure 7. The usual voltage on house mains is about 110 volts.

How much voltage is actually impressed on each of the 8 lamps? These lamps are rated at 12.5 volts, but the rating of a lamp or other apparatus cannot protect it from overload if the electrician or operator deliberately overloads it by a wrong connection.

Figure 7 shows 8 similar lamps. The total applied voltage is 110 volts. This voltage must all be lost or used up in the 8 lamps. Each lamp must assume its share, or ⅛ of the total. With 10 equal lamps in series, each one would have to take care of 1/10 of the total line voltage, but in Figure 7, each lamp must bear only ⅛ of 110, or about 13.7 volts. This is 1.2 volts too high (13.7–12.5) according to the rating of the lamps. These 13.7 volts will drive more current through the lamps than they were made to stand constantly, so they will burn up too rapidly. Whenever one lamp burns out, the others are temporarily saved, because no more current will flow.

How much current will this 8-lamp string draw from the line, if each lamp takes .5 ampere? In a series circuit, the current is the same in all parts; therefore, this .5 amp. will suffice to light all the lamps. Thus, the line current (I_L) will be only .5 amp.

How much resistance does each lamp have? By using 13.7 as the lamp voltage and .5 as the lamp current, the lamp resistance may be calculated by Ohm's law:

$$R = E \div I = 13.7 \div .5, \text{ or } 27.4 \text{ ohms for each lamp.}$$

How much will the total resistance of all 8 lamps in series be, allowing 27.4 ohms per lamp? This can be done in two ways. First, the total voltage and total current may be used (110 volts and .5 amp.).

$$R_t = E_t \div I_t = 110 \div .5, \text{ or } 220 \text{ ohms. Total.}$$

Second, another rule about series circuits may be used. In any series circuit, the total resistance equals the sum of all the series resistances. Thus, where the 8 lamps have 27.4 ohms each, as previously calculated, the total resistance

$$R_t = R_1 + R_2 + R_3 + \dots\dots\dots\dots, \text{ or}$$
$$R_t = 27.4 + 27.4 + \dots\dots\dots\dots, \text{ or}$$
$$R_t = 27.4 \times 8 = 219.2 \text{ ohms. Total.}$$

The slight difference (.8 ohm) is caused by the 13.7-volt value previously calculated being slightly in error, which also made a small error in the 27.4-ohm value.

Could this lamp string be protected better against lamp failure by using 9 lamps instead of 8 in series? Nine lamps would each absorb 1/9 of the total voltage of 110, or about 12.2 volts. This would be less than the 12.5-volt rating of the lamps, but not enough less to cause them to burn noticeably dimmer. Each lamp would then last much longer, not being overloaded (above rated values). The total current consumed by the 9-lamp string would be less than with 8 lamps, because of the larger total resistance. This ninth lamp, or socket and lamp, may be added anywhere in the circuit, say at place X, Figure 7.

What has been said about this series circuit is true in general of all series circuits to which Ohm's law applies perfectly.

13. Series-Circuit Law. In all series circuits:

There is only **one** path for the current.
Current is the same in all parts of the circuit.

$$I_1 = I_2 = I_3, \text{ etc.}$$

Total voltage = the sum of all series voltage drops.

$$E_{\text{total}} = (IR)_1 + (IR)_2 + \dots\dots\dots\dots$$

Total resistance = the sum of all series resistances.

$$R_t = R_1 + R_2 + R_3 + \dots\dots\dots\dots$$

These points are not very difficult to understand, and are very important in electricity.

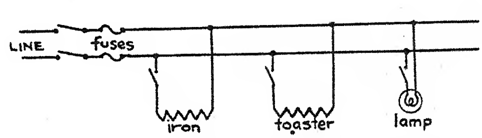


FIG. 8. Parallel circuit of home equipment.

14. Parallel Circuits. Parallel circuits are very common in household wiring. All the various lamps, the iron, the toaster, etc., in the average house are really in parallel connection, on the main line, as shown in Figure 8.

Figure 8 shows clearly that parallel circuits have more than one possible current path. These various paths are commonly called branch parts of the circuit. Each branch connects across the main line. Therefore, all branches are in parallel.

In any parallel circuit, all branches get the same voltage. In any house-lighting circuit, the main line delivers the same voltage to all floor sockets, lamp plugs, and any other connections. All common household equipment such as irons, lamps, etc., is rated at the same voltage, usually 115 volts (sometimes labeled 110–115 volts).

In Figure 8, if the iron draws 5 amperes, the toaster 3 amperes, and the lamp only 1 ampere, when all three units (or branches) are in use, the main line will have to supply a total of 9 amperes ($5 + 3 + 1$). None of the current in any one branch of a parallel circuit passes through any other branch.

15. Ohm's Law in Parallel Circuits. In applying Ohm's law to a parallel circuit, the caution of keeping all values of amperes, volts, and ohms referring to the same part of the circuit, must be observed. Figure 8 may be used to make this clear.

Allowing a current of 5 amperes for the iron, 3 amperes in the toaster, and 1 ampere in the lamp, how much resistance has each of these units? Note that these currents are forced to flow through the elements of the iron, toaster, and lamp by the same 110 volts supplied by the main line. To find R:

Ohm's law: $R = E \div I$ (values must all refer to the particular branch to be considered).
The iron: $R = 110 \div 5 = 22$ ohms.
The toaster: $R = 110 \div 3 = 36.7$ ohms.
The lamp: $R = 110 \div 1 = 110$ ohms.

How much is the total resistance of this parallel circuit? By using the total voltage (110) and the total current ($5 + 3 + 1 = 9$), the total resistance may be found.

$$R_{\text{total}} = (E_{\text{total}}) \div (I_{\text{total}}) = 110/9,$$
or about 12.2 ohms. Total.

Of course this is less than the smallest branch resistance, which is the iron with 22 ohms. In any parallel circuit the total resistance will be less than any of the branch resistances.

The reason for this can be shown by comparing the parallel branch resistors to various-sized doors in a large room. Suppose the room is crowded, and the people are trying to get out, in fact, are being pushed out. In this case the total resistance to the crowd of all the doorways **at once** is less than the resistance of any **one** door by itself, the other doors not being used.

By similar reasoning, in the case of electrical resistors, connected in parallel, it may be shown that the total resistance of several parallel branches (such as in Fig. 8) is less than the resistance of the smallest single resistor branch.

16. Parallel Circuit Law. In all parallel circuits: There is more than one current path; these are called branches. All branches connect directly to the main line.

Voltage of all branches is the same as the main-line voltage; all are equal.

$$E_L = (IR)_1 = (IR)_2 = (IR)_3, \text{ etc.}$$

Total current = sum of all branch currents.

$$I_{\text{total}} = I_1 + I_2 + I_3 + \dots\dots\dots\dots$$

Total resistance of all branches is less than that of the smallest branch.

It is necessary that these points are understood.

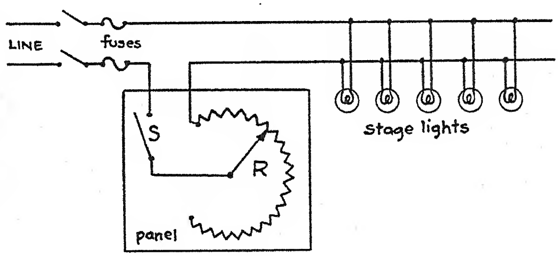


FIG. 9. Stage-lighting-circuit controls.

17. Controlling Current Flow. Switches and rheostats offer a means for completely controlling the amperage, at will. Consider such a circuit as shown in Figure 9, where a scheme is diagramed for controlling stage lights in a theater.

Here, the main line is equipped with a safety switch and fuses in a manner similar to the average house electric system. In addition, a special panel is so wired that the operator may "cut" the lights entirely or slowly dim them in a "fade." The switch *S*, and the special heavy-duty rheostat *R* (variable resistor) permit him to do this, as he pleases. When several such circuits are provided in a large theater, with each separate circuit controlling lamps of a certain color, fading light color from blues to reds, or from golds to greens, is easily accomplished. Slowly dimming one set while slowly brightening another makes the color change so slowly and evenly that it is hardly noticed by the audience.

Switches and rheostats are useful in controlling many other electrical circuits. To increase the resistance will cut down the current. To decrease the resistance will raise the current. Of course, such heavy-duty, constant-service rheostats must be made of materials that will not burn or melt from the heat necessarily produced by them. More will be said about this in the chapter on Resistance.

18. Circuit Faults. Electric circuits sometimes develop faults, or "troubles," that are dangerous to them and to anyone near them or touching them. The commoner faults are listed here as a matter of general interest.

Open Circuit. When a wire or line breaks or burns out, the fault is called an **open circuit**. A new metallic connection must be made, to repair the fault. Example: a broken trolley wire.

Ground. When a wire, which should be insulated from the earth or the frame of a machine, gets connected to the earth, or frame, it is said to be **grounded**. Reinsulation is necessary. Example: a telephone or power line rubbing tree branches until the insulation on the wire is worn through and the bare wire "grounds" through the tree wood.

Short Circuit. When some other (and usually shorter) path is forced by the current, other than the path properly provided, the circuit is said to be **shorted**. Example: high-voltage transmission lines on a pole flashing over between them. A wider spacing or heavier insulation is needed in this case.

SUMMARY

Electrons are small, invisible particles of electricity.

Conductors are materials through which electrons can flow.

The **ampere** is the unit of current, or about 6.3 quintillion (6,300,000,000,000,000,000) electrons per second.

The **volt** is the unit of electrical pressure.

The **ohm** is the unit of electrical resistance.

Ohm's law applies to all electrical circuits.

$$E = IR;\ R = E \div I;\ I = E \div R$$

where E = voltage, expressed in volts,

I = current, expressed in amperes, and

R = resistance, expressed in ohms.

Ammeters are always connected **in** the line.

Voltmeters are always connected **across** the line.

Series circuit law: Only one path for the current.

I in all parts of the circuit are equal.

E_{total} = sum of IR drops of all the parts.

Parallel circuit law: More than one path for the current.

E across all branches are equal.

I_{total} = sum of the I in all the branches.

PROBLEMS

Prob. 1. Show an enlarged view of a section of a wire carrying current. Indicate the particles of the wire by shading, and show how electrons might move through the wire.

Prob. 2. How many electrons in a coulomb of electricity? Why is a coulomb per second a more practical unit of current than an electron per second?

Prob. 3. An ampere is a coulomb per second. If the current is 5 amperes for 10 seconds, how many coulombs pass?

Prob. 4. Find the average current in amperes, when 75 coulombs pass in 5 seconds.

Prob. 5. Explain how the cross-section size and material used in a wire affect its resistance to a flow of current. Illustrate with enlarged views. With twice the resistance, how much less current will flow? With one third the resistance? Assume E does not vary.

Prob. 6. Make a list of the kinds of insulation used in household electrical apparatus, such as irons, iron cords, sweepers, toasters, lamps, etc.

Prob. 7. Why are cords for electric irons made of stranded wire instead of solid wire? Why are they usually wound with asbestos cord, outside the rubber wire covering?

Prob. 8. Illustrate the advantage of symbols over pictures, in diagrams. Make a wiring diagram of a doorbell circuit that may be operated from either one of 2 separate push buttons.

Prob. 9. Diagram a 25-ohm resistance connected across a 100-volt line. How much current will flow through this resistor?

Prob. 10. Show a 10-ohm resistor, drawing current from a 65-volt line. Find the current.

Prob. 11. Show an ammeter connected in the line to a resistor, and a voltmeter connected across the resistor. Suppose the voltmeter shows a drop of 20 volts across the resistor, with a current of 8 amperes. Find the resistance.

Prob. 12. Two resistors, 6 ohms and 4 ohms, are connected in series on a 120-volt line. Diagram the circuit. Find the total resistance; the current flowing; the voltage drop across each resistor.

Prob. 13. A 4-volt lamp is to be connected across a 6-volt battery. Diagram the circuit, showing the necessary series resistor. How much voltage must this resistor absorb? With a current of .5 amperes in the lamp, how much resistance should the resistor have? The lamp?

Prob. 14. A string of 10 ordinary 110-volt lamps is connected in parallel, to floodlight a small stage. Each lamp requires .5 amperes. Find the total current. What voltage should be on the line to the lamps?

Prob. 15. Diagram the lamps in Problem 14 connected in series. Find the necessary voltage on the line, and the total current drawn. Would this current connection be practical? Safe?

Prob. 16. Diagram six 15-volt lamps connected in series on a 120-volt line. Show that each lamp gets too much voltage. What will probably happen to the lamps? How can it be avoided?

Prob. 17. The two 110-volt lamps in a chandelier are connected by mistake, in series, on a 110-volt line. Each lamp has 220-ohms resistance, and is rated at .5 ampere. Find the total resistance, as connected, and the actual current in each lamp.

Prob. 18. A one-horsepower d.c. motor draws about 4 amperes on a 230-volt line. How much resistance has this motor? Find its current on a 200-volt line.

Prob. 19. A farmer attempted to use a standard 110-volt, 5-ampere electric iron on his 32-volt farm-lighting circuit. Find the iron's resistance; find its current on the 32-volt line.

Prob. 20. If a 220-volt lamp, rated at 1 ampere, is put in a 110-volt socket, how much current will it draw? Will it fully light? Why?

Prob. 21. A voltmeter and a special ammeter are connected in series across a d.c. line. The voltmeter reads 75 volts, at .005 amperes. Calculate the resistance of the voltmeter.

Prob. 22. In Problem 21, the voltage drop across the ammeter is found to be about .0005 volts. What is its resistance?

Prob. 23. Diagram an automobile lighting circuit. All circuits must

have a switch in the line, and all are connected in parallel across the main storage-battery line.

Prob. 24. Suppose an automobile ignition circuit develops a .5-ohm short somewhere. On a 6-volt battery circuit, how much current will flow in the short?

Prob. 25. An ammeter having .01-ohms resistance is accidentally connected across a 100-volt line. Find the current tending to flow in the meter. Would the ammeter be damaged?

Prob. 26. An ammeter is used to test a 1½-volt dry cell. If the current through the meter is 30 amperes, how much is the resistance of the meter?

Prob. 27. A trolley line has a voltage drop (wire and rail together) of 90 volts, when a 150-ampere current is drawn. Find the resistance of the circuit.

Prob. 28. An electric curling iron, that draws .2 amperes at 105 volts, is plugged in on a 125-volt line. How much current will it then draw? (Find resistance first.)

Prob. 29. If a screw driver (say .01 ohms) shorts across the 6-volt terminals of a storage battery, how much current will flow in this short circuit?

Prob. 30. A certain long-distance, 11,000-volt transmission line has 50-ohms resistance. Find the voltage drop at 25 amperes. What will the voltage be at the end of the line?

Prob. 31. At 1100 volts, the line in Problem 30 must carry 250 amperes to deliver the same power as it does at 11,000 volts. How much voltage would be lost in this case? Would the line be practical at 1100 volts?

Prob. 32. At 110,000 volts, how much voltage drop would occur in the transmission line of Problem 30? The current would then be only 2.5 amperes to deliver the same power.

Prob. 33. How many more times the insulation value would the 110,000-volt line require than the 11,000-volt line? Why?

Prob. 34. With aluminum wire for high-tension lines, can the supporting towers be spaced further than with copper wire? Aluminum has 1.75 times the resistance of copper, but is only about .3 as heavy as copper. (See Table XII.)

Prob. 35. Arc lamps used for street lighting have a voltage drop of about 40 volts, at about 35 amperes. If 72 arcs of this type are operated in series, how much current will be drawn by them? What operating voltage will be required at the substation, disregarding any other line drops?

Prob. 36. If four of the lamps in Problem 35 short circuited, what should be the operating voltage of the circuit? How much will the current be?

Prob. 37. A country telephone line must deliver .02 ampere to the customer's receiver, through a line having a resistance of 150 ohms. How much must the talking voltage be?

Prob. 38. A fallen trolley line touches a rail. Will the line current tend to be greater or less than normal? Why?

Prob. 39. If a 1-inch air-gap spark gap in a high-voltage circuit breaks down and allows .001 ampere at 80,000 volts, about what is the resistance of the gap at that instant?

Prob. 40. A man's average hand-to-hand resistance is about 300 ohms, and he can safely stand up to .3 ampere if it does not pass through or near his heart. What is the maximum voltage to which he should expose himself?

THE ELECTRIC ARC AS A TOOL

Two thousand degrees of heat can be obtained by an electric arc, to cut or fuse steel rails. The same electrons that cause this extreme temperature came to the job in a cool, copper trolley wire! The high resistance of the gap of the arc is the cause for the heat.

The workman wears a heavy eyeshield to protect him from the very dangerous rays generated by the electric arc. Rubber gloves and heavily insulated cables protect him from shock.

Chapter II

CURRENT: ELECTRONS FLOWING

TWO kinds of current are in general use: **Direct** current and **alternating** current. Direct current is usually abbreviated d.c., and alternating current a.c.

If current always flows in one direction and never reverses, it is called direct current. But if the current reverses direction, flowing first one way in the circuit, then the other, it is called alternating current. All batteries supply d.c. Most power lines, house-lighting lines, and all transformer circuits are a.c. In a d.c. circuit, both voltage and current are direct; that is, they never reverse, although they may vary in value.

20. Current in the Home. In recent years, many laborious household tasks have been taken over by electricity. The electron has become the modern slave in most homes, doing a large share of the harder tasks such as washing, ironing, and cleaning. Even bread mixing and cream whipping are being done by motor-driven kitchen devices. Added to these services are the modern electric light, the radio, electric refrigeration, and electric heaters, that make the wall socket a source of many widely different marvels of modern civilization. Table V lists a few values of current used by some household electrical devices.

TABLE V. COMMON CURRENT RATINGS

	Amperes
No. 6 dry cell, on short	about 30.
25-watt lamp, on 120-volt line	.21
40-watt lamp, on 120-volt line	.33
60-watt lamp, on 120-volt line	.5
Standard 600-watt iron, on 120-volt line	5.
½-horsepower motor, on 120-volt line	4.
10-in. fan, 25 watts, on 120-volt line	about .21

Curling irons, electric soldering irons, reflector heaters, toasters, and similar equipment have various current ratings, depending on their size and construction. It may be of interest to know that, in any case, the current drawn by an electric heating device can be easily calculated. Divide the watts shown on the name-plate of the device by the line voltage. The answer thus obtained will be the amperes drawn by the device at that voltage. Check the current ratings of the lamps and the iron in Table V by this method.

Several effects of a current in a wire need to be mentioned here. Of course, everybody is aware of the shocking effect of current. This is a very dangerous effect, and no one should ever expose himself carelessly to shock of any kind, because a very bad injury may be sustained. Care must always be exercised by anyone, when working with any circuit of more than 100 volts, to provide enough good insulation with gloves and rubbers to prevent possible shock. An ounce of such prevention is well worth hours of artificial respiration applied by a rescue crew, any time.

Several useful effects of current, however, such as heating, magnetic, and chemical, will be discussed and illustrated. Many interesting experiments may be tried, using simple equipment.

21. Heating by Electricity. Perhaps the largest use of electricity in the average modern home is in heating various devices, such as irons, toasters, and percolators. All of these devices depend on the heating effect of a current when forced through some resistance material. The kind of metal used for the resistance, and the length of it, of course, affect the resistance, as well as the amount of heat. The amount of heat developed depends on the current forced through the heater unit. An experiment will make this clear.

Experiment 1. Make two heavy lead (pronounced "leed") wires, about 12 in. long. These should be about No. 18 wire, insulated, like that used for bell circuits. Scrape each wire clean of insulation for 1 in. at each end. Get short samples of the materials you wish to test for their electric heating qualities, some of which are suggested in Table VI.

Twist the heavy lead wires tightly around the ends of a sample of material to be tested, as shown in Figure 12. Be sure to make good joints at the points *X* and *Y*. Scrape the ends of the wires

and the sample clean of dirt or insulation before twisting together.

Now hold the heavy leads on the terminals of a dry cell.

TABLE VI. MATERIALS TO BE TESTED FOR HEATING

1. Very fine copper wire, about 3 ft. long
2. Very fine copper wire, about 1 ft. long.
3. Very fine copper wire, about 3 in. long.
4. Iron wire (stove-pipe wire), various lengths.
5. Tinfoil, rolled up into a small, tight roll.
6. Tinfoil, strip about ¼ in. wide and 3 in. long.
7. Roll of blotting paper, soaked in strong salt water.
8. Fine wire hairpin (usually a cheap grade steel).

Do not use house lines in this test, because the resulting short circuit would blow the main fuse and perhaps damage house wiring. Do not fasten the leads under the brass terminal nuts; touch the leads to the terminals for only a few seconds. Notice what happens to the sample. Does it heat up? How hot does it get? Does it burn up? Does the length of the sample affect the heat? Why? Does the material itself affect the heat?

Keep a sketch of your experiment and notes on what you discovered about the heating effect of current in the various samples tested.

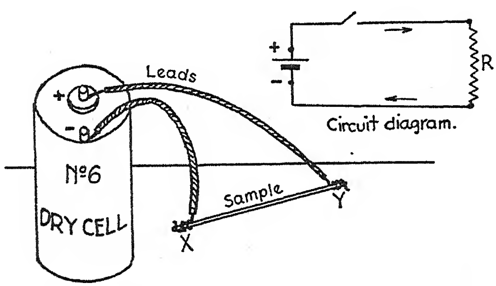


FIG. 12. Experiment to show heating effect of current.

22. Uses of Electric Heating. The heating effect of current in a conductor can be put to many common uses. Most homes use electric irons and electric lights, the two most widely used

devices that are operated with electric heating. Of course, the electric iron is not heated to as high a temperature as the electric-lamp filament. The amount of heat to be delivered by the device must be taken into consideration by the manufacturer. Table VII shows some common electric heating devices, listed in order of approximate usual operating temperatures.

TABLE VII. DEVICES UTILIZING ELECTRIC HEATING

	Degrees F.
1. Filament in 100-w. lamp	about 4000
2. Filament in 40-w. lamp	about 3200
3. Filament in 25-w. lamp	about 2800
4. Electric steel furnaces	about 2500
5. Electric heater, reflector type	500 to 700
6. Electric soldering iron	about 500
7. Electric toaster	about 300
8. Electric stove	250 to 550

To this small list may be added many more devices, such as electric curling irons, percolators, hotplates, milk warmers, and heating pads. But regardless of the kind of heating device considered, the principle is always the same.

The heat is caused by a great many electrons being forced through some part of a path that has resistance. Even a copper trolley wire gets hot when the cars on the line draw very heavy current. Notice that ice or snow do not cling to main-line trolley wires. These lines are usually quite warm, even in winter.

Any wires that must safely carry heavy currents must be carefully chosen to be large enough in size so that little or no heat will develop. This is especially true of any wires that are enclosed in walls, such as house circuits, where excess heating may cause fire. While in the electric arc furnace and like devices heat is desired, in many other cases heat is dangerous, and certain precautions must be taken against overheating.

23. **Dangers from Electric Heating.** In such machines as electric generators, motors, and transformers, the heating effect of the current in the conductors is never desired. But because all wires have some resistance, any current through them will develop some heat. This heat, in machines not designed or

intended to get hot, represents a waste of valuable energy. For example, when a motor runs too hot, it is less efficient than when it runs cool. The same is true of other electric devices such as generators, electromagnets, and batteries. Overheating from too much current may result in damage such as:

Charring of Insulation. Ordinary insulation on wires is cotton or rubber. These will burn up when the wires inside get hot, and allow the wires to ground or short, thus causing further damage to the circuit.

Melting of Conductor. Small copper wires will melt at high temperatures. Sometimes the wires actually burn up in a flash, as occasionally happens with iron cords inside the iron plug. Poor connections are usually the cause of these flashing arcs that melt the wires off quickly.

Fire in the Machine. Large motors and generators sometimes take fire, under severe overloads that last too long. Of course, such fires, even if extinguished immediately, are likely to ruin the machine. In most cases, the machine must be completely rewound and rebuilt.

Arcing. Excessive heat in a machine often results in the starting of an arc, which further destroys the insulation and conductors. This happens in motors at the commutator, when operated above rated current and voltage values. The commutator bars burn badly, or pit, from such arcs at the brushes.

To guard against overcurrent in all kinds of electrical equipment, some kind of protecting device, such as a fuse or circuit breaker, must be used.

24. **Protection from Heating Effect of Current.** Fuses offer the usual method of protecting a line or a piece of electrical equipment from overload, undue strain, and the attendant heating effect. Circuit breakers also are used as automatic switches, to open the circuit when the current gets above the amount allowed. Fuses and circuit breakers can both be made to open the circuit at any predetermined value.

Fuses are made in several types. The common type used in the fuse box in a home is called the "plug fuse." This is mounted in a screw base, similar to a standard lamp base, and screws into a fuse block usually enclosed in a safety switch box. When

the safety switch box is correctly made and installed, the line switch must be open, with no power on the house side of the switch, before the fuse compartment can be opened. Plug fuses have windows of clear mica, through which the fuse itself can be inspected.

Automobiles sometimes have small cartridge-type fuses. These are usually made with glass tubes to show up the fuse wire inside. But, regardless of what type of case a fuse is made in, it always operates on the heating effect of a certain amount of current passing through it.

For example, suppose a house line can safely stand only 40 amperes without overheating the wires inside a wall. If somebody connects a 1-ohm resistor on the 110-volt line, 110 amperes will tend to flow in that circuit. This heavy current is practically a short-circuit current, in this case, and will soon heat the house wires to a red heat.

But, if somewhere in this line, there is a 40-ampere fuse, no such current as 110 amperes will be allowed to flow in the circuit. At 40 amperes, the fuse will get soft and melt, cutting off all further current. The fuse link melts because it is made of a material, usually a low melting alloy of lead, that will melt from the heat of the rated current through it. A 30-ampere fuse will melt out at more than 30 amperes.

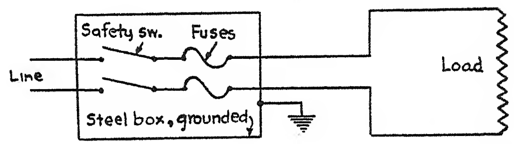


FIG. 13. Correct connection of safety switch and fuses.

The diagram in Figure 13 shows the place of the fuse in a circuit. While one fuse in one of the wires to the resistance or load might be sufficient protection, it is well to use a fuse in each of the line wires, to protect against a ground in the equipment. In certain types of ground fault, one fuse might not blow out soon enough. The fuses should always be connected on the load side of the main switch. This allows a change of fuses, with the power entirely cut off, and no danger of shock.

Never use such things as pennies or copper wire for "fuses."

These materials can stand a much higher current than the lead-fuse link. The high current necessary to blow or melt such a substitute for a real fuse might allow house lines to overheat or the "protected" equipment to burn up.

The lead link in a fuse is usually made smaller at the middle, to insure melting through at the proper rated current value. Examine a fuse in a house circuit. Fuses are usually made as shown in Figure 14.

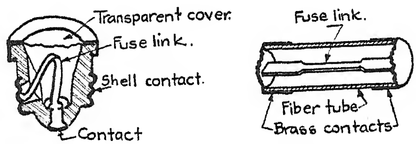


FIG. 14. Plug fuse and cartridge fuse.

In choosing the correct rating of fuse to use in any line, add up all the currents to be drawn on that line at any one time. Then use a fuse of slightly higher value than this total. For example, suppose a line supplies these currents to equipment operated at the same time:

Electric iron	5 amperes
½-horsepower motor, starting current of	25 amperes
Two 60-watt lamps, ½ amp. each	1 ampere
Total	31 amperes

In this case, a 35-ampere fuse would provide for a slight increase in current on the line, and yet protect the line from excessive current caused by shorts or grounds. Note that motors always draw more current in starting than when running at their rated speed. On small motors, allow about 6 times the running current for starting the motor. (Check with Table V.)

25. Current, Flux, and Magnetism. A very useful effect of current is called the magnetic effect. Whenever a current flows in a wire, magnetic flux is set up around the wire. The same thing is true of a coil of wire which carries a current. A magnetic flux is set up around that coil. It will be simpler to understand

all this if some facts about permanent magnets are first set forth.

Permanent magnets always are made of a good grade of hard steel. The steel bars may be magnetized by putting them in a very strong magnetic field such as exists in and around a coil of wire carrying a current. The more turns and the greater the current in the coil, the more intense the field or flux will be. In a very intense magnetic field, a bar of steel becomes a very strong permanent magnet. A simple experiment will bring out many details about magnets and flux.

Experiment 2. Materials needed: a No. 6 dry cell; about 25 ft. insulated wire, No. 24; a medium-size thread spool; several nails, tacks, pieces of iron wire, hairpins, and other samples of metals. Do not use a transformer as a current source, here. Transformers supply only alternating current. Direct current is desired for this particular experiment.

Wind some of the insulated wire on the spool. Seventy-five turns will be sufficient. Leave long leads on this coil to connect to the battery. Curling up part of these leads, on a pencil, will make "pigtails" or more flexible leads than if the extra wire is left straight.

Connect the coil to the battery. This current-carrying coil will now have lines of magnetic flux around it, as shown in Figure 15.

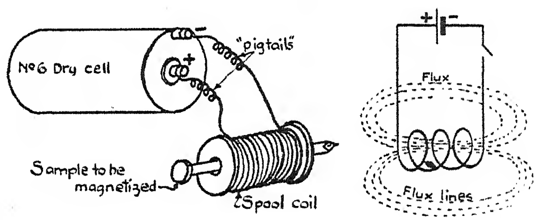


FIG. 15. Making magnets by electricity.

Put a long nail into the hole in the spool. Nails are soft steel, but will hold magnetism fairly long if kept in a very strong magnetic field for about 5 seconds. Remove the nail from the coil, and disconnect the coil at one battery terminal, to save the battery from drain when not needed. A small switch in the line may be used to open the circuit, if desired.

The nail, when removed from the coil, will be found to attract other iron or steel objects, such as small tacks or iron wire. The nail has become a "permanent" magnet. This magnetism will not last very long, but any magnet that has a field without the aid of a current in a coil around it is called a **permanent magnet.** Try this with iron wire, copper wire, a match stick or wooden pencil, etc. What materials can be magnetized?

Reconnect the coil to the battery. Bring a small tack or piece of iron wire near one end of the spool hole. Notice how the flux of the spool coil draws the magnetic material into the hole. Is the coil, when carrying current, a kind of magnet? Does the coil get quite warm? Why?

Open the circuit. Can the iron wire or tack be easily withdrawn from the coil? Is the coil a permanent magnet? Reverse the leads to the dry cell, and see if the same procedures will give the same results as before. Keep a good record of the way the coil was wound, the circuit used, the experiments tried, and the results of each case. There will be more interesting experiments related to this one, and these records will save time and allow comparison of results in a better fashion than if remembered only vaguely.

26. The Law of Magnetic Poles. A magnet always has two poles, one North (N) and one South (S). One magnet never has three poles, and the poles always occur in N–S pairs. That is, for every N pole in a motor there is an S pole.

Motors utilize several features of magnets to get the strongest action from the least power. Motors will be discussed in a later chapter, but the magnetic laws which govern all motors can be easily shown by an experiment.

Experiment 3. Materials needed: a No. 6 dry cell; wire and spool for a coil as in Experiment 2; two hard steel screws, or two large hard nails; some light string or thread.

Wrap about 75 or 80 turns of wire on the spool, as in Experiment 2, leaving long leads for connection to the battery. Mark one end of the spool coil with an X so it can be distinguished from the other end. Connect one lead to the + or middle terminal of the battery. Leave the other lead loose so it may be touched to the other battery terminal when current is desired in the coil. A switch may be used here as in Experiment 2, if desired. Figure 16 shows these details.

Put a long, steel screw into the end of the coil marked X, as shown. Touch the — lead to the battery terminal, and allow current to flow for about 15 or 20 seconds. This will permanently magnetize the screw. Lay this screw aside, to be used later. (Nails may be used in place of screws, but are not as good.)

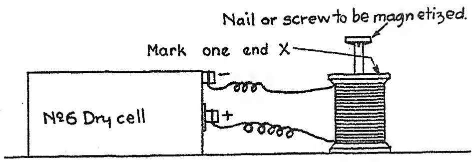


FIG. 16. Making permanent magnets for Experiment 3.

Do exactly the same with another screw similar to the first one. When this screw (or nail) is magnetized permanently, remove it from the coil field and open the battery circuit. Because both screws were treated exactly the same way, they will have similar magnetic poles at their heads and similar opposite poles at their points.

Now hang these two magnetized screws on thread or string as shown in Figures 17 and 18. Tie the thread on a screw, and adjust it until the screw balances on the thread. Each thread should be about 12 in. long.

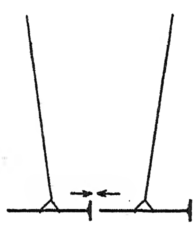


FIG. 17. Unlike poles attract.

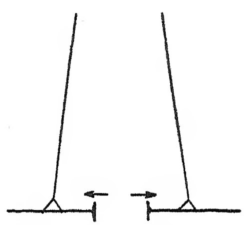


FIG. 18. Like poles repel.

Hold a thread in each hand steadied by something as, for instance, a chair back. When the screws are balanced and at rest on their threads, move the top ends of the threads slowly closer together. Notice how the screws, which are little magnets, act on each other. Try to get two heads or two points to touch.

Do the two heads attract or repel? Are the heads the same polarity, that is, both *N* or both *S*? Were they made to be like poles? Do like poles attract or repel?

Do the two points attract or repel? What does this prove?

Does head No. 1 attract or repel point No. 2? How about head No. 2 and point No. 1? What does this prove?

Magnetize two large-headed, smooth-shanked nails, as in the beginning of this experiment. Lay the nails on rollers such as small pieces of straight macaroni, so they can roll together or apart as they obey the law of magnetic poles. See if the results of this experiment check the law that:

> Like magnetic poles repel or push apart.
> Unlike poles attract or draw together.

It would be well to try the whole experiment again, after reversing the coil connections or using the end of the coil opposite the one marked X. Keep notes on the experiment.

27. Construction of a Magnetic Compass. Historical records suggest that the ancient Chinese had compasses long before Europeans reinvented them. The compass is a very valuable instrument to seamen, explorers, and surveyors.

A magnetic compass is a small permanent magnet, balanced nicely on a needle point, so it may adjust its position in accordance with the law of magnetic poles. The *N* end of this little steel magnet will always try to point to the *S* pole nearest it.

A magnetic compass, with a neat brass case with glass cover and a carefully balanced needle, may be purchased. But a reasonably accurate compass, that will serve in several later experiments, can be made.

Experiment 4. Making a magnetic compass. Material needed: one darning needle about 2½ in. long; a No. 6 dry cell; a spool coil, such as used in Experiment 1; a common pin; some stiff cardboard.

Connect the coil to the battery as in Experiment 1. Put the needle in the spool coil, and strongly magnetize it. This will require about 10 seconds in the field. Open the battery circuit to prevent unnecessary battery drain. Remove the needle. Details are shown in Figure 19.

Make a small cardboard base for the compass, with a common pin pushed up in the middle of the card, as shown in Figure 20.

The *N*, *E*, *S*, and *W* marks may be neatly printed on the card. The magnetized needle may be supported by a small bearing made of cardboard, cut and bent as shown in the detail. Do not

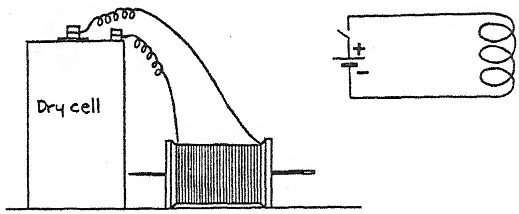


FIG. 19. Magnetizing the needle for a compass.

push the needle bearing down on the pin point; merely rest the needle bearing lightly on the pin point, with the needle against the side of the pin. This will allow the magnetized needle to turn in accord with the flux lines around it.

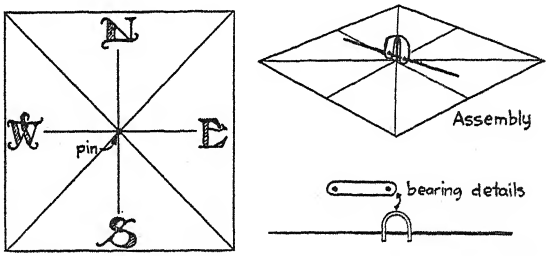


FIG. 20. Details of magnetic compass.

Such a compass will detect even very weak flux fields, such as the earth's field at any point. The earth has two magnetic poles. The magnetic *N* is in North America, near Hudson's Bay. The magnetic *S* is just about opposite the earth's *N* pole, in Antarctica near South Victoria Land.

The *N* pole of a magnetic compass will point to the strongest *S* pole near it. The *S* pole of the compass will be attracted toward the strongest *N* pole near it. This follows from the law of magnetic poles which states that only unlike poles attract.

Any iron, steel, or other magnet near a compass will make

the needle swing toward it, depending on how large the iron is and how strong a field it has. Try this out on the compass just made. Bring a steel knife blade near the needle. Notice how the needle swings away from its true *N* position, toward the steel. If another magnet of any kind is brought near the needle, one end of the compass turns toward the magnet. Try this out with a permanent magnet and an electromagnet (coil carrying current). Will a magnetic compass register the true *N* of the earth, when used on a steel ocean liner? Why? Even wires carrying heavy current near a compass will disturb its direction accuracy. Why?

28. Construction of an Electromagnet. A coil of wire, when carrying current, is one kind of electromagnet. If the coil has a soft iron core, it is a much stronger electromagnet than when any other kind of core is used. The reason for this is simple enough. "Soft" iron, or iron that has no carbon mixed with it as has steel, allows flux to pass through it easier than any other material passes flux. Therefore, with an iron core in the center of a coil, flux can and does pass in a larger amount. The same current in the coil thus causes more flux around the coil, making a stronger magnet.

An electromagnet can be made in many ways. The use of the finished magnet determines its shape and strength. The current it is to use determines the size of wire to be wrapped on the iron core of the magnet. For example, the electromagnets in a telephone receiver must operate on a very small current. These coils are wound with several hundred turns of enameled wire about No. 40 gauge, which is as fine as hair. On the other hand, magnet coils of a bell operate on a much larger current. These are wound with about 100 turns of No. 26 gauge cotton-covered wire. The great electromagnets used with big cranes to lift iron and steel material are wound with turns of very large copper bar. Some of these big magnets can lift many tons of iron or steel safely, yet release their load instantly when the switch is opened by the craneman or operator.

Experiment 5. Making a small electromagnet. Materials needed: about 25 ft. of cotton-covered or enameled wire — No. 24 or No. 26 gauge will do nicely; a soft-iron stove bolt or carriage bolt, ¼-in. shank, about 1½ in. long, with a large square head and nut; some stiff cardboard, and some heavy wrapping

paper. A No. 6 dry cell will operate or energize the finished magnet, which will have a lifting power of about 2 ounces.

From the cardboard cut two similar washers about ¼ in. larger than the bolt head and nut. Make holes in the center of these washers, so they fit the bolt shank snugly.

Push one washer down against the bolt head. Put the other one in place on the shank of the bolt with enough room left for the nut to be even with the bolt end, as shown in Figure 21. Cut a 4-in. long strip of heavy wrapping paper wide enough to wrap around the bolt between the cardboard washers or coil ends. This paper may be kept in place with a little glue, paste, or thread.

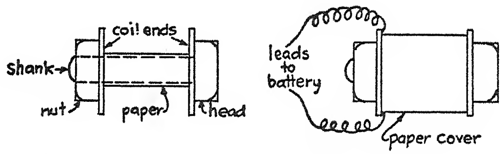


FIG. 21. Details of simple electromagnet.

Straighten out the wire to be wound on the magnet core so that it has no kinks or tangles. Begin winding from the nut end of the magnet, leaving about 6 inches of wire for a lead.

Wind one layer of wire smoothly across the paper-covered core, from one cardboard end to the other. Wind the next layer of turns in the same direction, but coming slowly back toward the nut end of the magnet. Keep the turns tightly against each other so the layers will be smooth. Wind on all the turns possible with the wire available, making as many layers as needed. Try to have the last layer wound toward the nut, so the lead wire will come out this same end of the magnet as does the other lead. About 125 turns may be wound on this magnet, with 24 ft. of wire.

Cover the outside of the winding with another strip of heavy wrapping paper, glued or pasted on. The electromagnet is now ready for use in many experiments.

Connect the leads to a battery. Test the strength of the magnet by counting or weighing the objects it can lift. Notice how its strength is greatest against the bolt head, or pole face as it is called in electrical terms. Does reversing the leads to the battery change the magnet's strength?

Experiment 6. Flux of an electromagnet. Materials needed: the electromagnet of Experiment 5; a battery; some small steel brads or tacks.

Hold the magnet with the core horizontal. Try to build up two "chains" of small nails or tacks from one pole to the other, as shown at A, Figure 22.

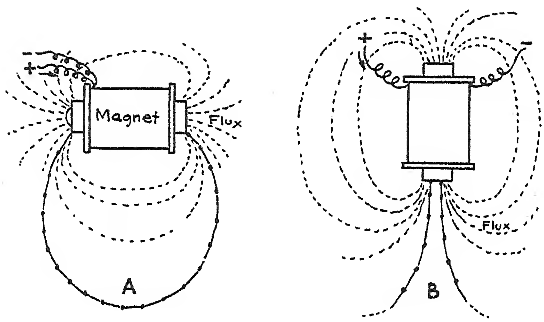


FIG. 22. Flux lines demonstrated with an electromagnet.

This shows that the flux that leaves one end of a magnet goes back in the other end of the same magnet. The flux comes out of an *N* pole and returns to the *S* pole. Inside the magnet, of course, the flux goes from *S* to *N*, and out again.

Try the same experiment with two chains of tiny brads on the same end of the magnet, as shown at *B*, Figure 22. Why do the chains tend to spread apart? Does this prove the law that like poles or like flux lines repel? Reverse the battery connections and repeat this experiment, to be sure the same results will be observed. Keep a record of these findings.

29. Testing for the *N* and *S* Poles. Many times the definite polarity of a magnet needs to be known. For example, motor magnets, where the leads do not show the winding direction, must sometimes be checked for polarity. Compasses themselves must be checked, to be sure which end is *N*.

Sometimes watches become accidentally magnetized by being placed in the strong field of a large electromagnet, motor, or generator. Watches of substation men are often magnetized. In any case, the fine steel hairspring of the escapement, when magnetized, will not allow the watch to run accurately, and

often stops it completely. Jewelers must have a simple, sure way to determine whether or not the steel parts of a watch are magnetized.

A finely balanced, strongly magnetized compass needle will readily detect magnetism and show whether it is *N* or *S* polarity.

Experiment 7. Determining magnetic poles with a compass. Materials needed: compass such as made in Experiment 4; coils, magnets, etc., to be tested.

Be sure the compass needle is strongly magnetized, and nicely balanced so it swings freely on the pin point. Check its earth-*N* finding ability several times. Set it on a wooden table, free from jar or vibration. Let it come to rest toward the earth-*N*.

Bring the sample or piece of metal to be tested for possible magnetic flux near one of the compass-needle poles. If the *N* end of the compass swings **toward** the sample, this only indicates that the sample is iron or steel. But if, when the same sample is brought near the *S* end of the compass, this *S* end swings **away** from the sample, it shows that the sample must also be *S*. Why? What reaction of the compass will prove an *N* pole on the sample? Why?

If both *N* and *S* ends of the compass attract equally to the tested sample, the sample is neutral or not magnetized.

If neither end of the compass needle attracts to the sample, the sample must be nonmagnetic material.

Try out these experiments with the compass. Test a coil of several turns, carrying current. Reverse the coil and note what happens. Try the center of a long coil, wound on a wooden pencil for a core. Where are the poles of a coil? Are both poles the same?

Magnetize two similar needles at the same time in a small coil, as in previous experiments. Place these needles with the same poles equally distant from the compass. What happens? Reverse one needle, but do not change its general position. Now what happens? What two forces are now acting on the compass poles? A good motor uses the attraction of unlike poles and the repulsion of like poles at the same time.

As the magnetized needles are moved farther away from the compass needle, how do they affect the compass? Be sure you keep notes with neat sketches on these findings.

30. The R.H.R. for a Straight Wire. The right-hand rule, as it is known commonly, is merely an easy way to remember which way the flux flows around a straight wire carrying a current.

It is quite interesting to experiment with coils and magnets, to find out how the presence of a current in a conductor always sets up a magnetic field around a wire. Later, it will be shown that flux set up around a wire causes a current to flow in the wire. Flux and current are definitely related, yet strangely enough are not at all the same thing.

Experiment 8. Detecting the flux around a conductor. Materials: a No. 6 dry cell; about 6 ft. of insulated wire, about No. 26 gauge; a magnetic compass.

Connect the wire to one terminal of the battery. Have the other end of the wire in a position that it can be easily touched to the other battery terminal to complete the circuit, when desired. A small knife switch in the line also may be used to do this. Figure 23 shows the general arrangement of the experimental apparatus.

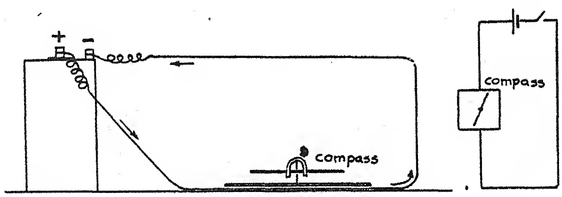


FIG. 23. Detecting flux around a wire carrying current.

Set the compass on top of a straight part of the wire. Arrange the wire and compass so that the needle is at rest in the earth's N flux with the needle **parallel to the wire.**

Now close the circuit at the battery, without jarring anything. What happens? What does this show? Open the circuit. Does the needle come back to the first position? What causes the needle to come back there? Is there any flux that is always present at any place? What is its source?

Reverse the current in the wire. How does this affect the results? All this can be summed up in one rule that will cover all cases of flux around a straight wire carrying current. The

two possible current directions in a wire are shown by small arrows in Figure 24. The corresponding flux directions, as proven by the experiment with the magnetic compass, are also shown.

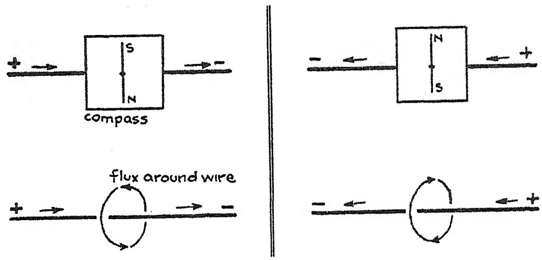


FIG. 24. Flux direction around a wire carrying current.

Imagining the right hand grasped around the wire, with the thumb in the direction of the current in the wire (+ to —), the fingers are around the wire in the direction of the flux caused by the current. Thus the right-hand rule for a straight wire is:

Thumb in direction of *current* in the wire.
Fingers around wire in direction of *flux.*

This is illustrated in Figure 25. Never actually hold the wire, because it may be carrying very high voltage. Merely imagine the right hand on it, thumb in direction of current.

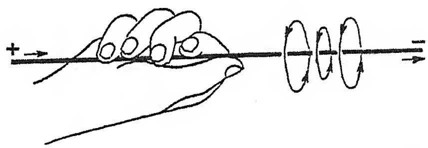


FIG. 25. Right-Hand Rule for a straight wire.

Try out this rule on the wire, with the compass as a positive check on the accuracy of the rule. Try the compass underneath a straight section of the wire. Note the direction of the compass, and check with the right-hand rule. Reverse the current, and try this over again. All cases should check; compass test and rule application should give the same result.

Do not keep the circuit connected long at a time, or the battery will be overworked and drain quickly.

Try the same experiments with the wire doubled back on itself, as shown in Figure 26. If the compass needle fails to move, does this prove conclusively that no flux is set up? Separate the wires an inch, and repeat the test. Try the needle directly over one wire at a time.

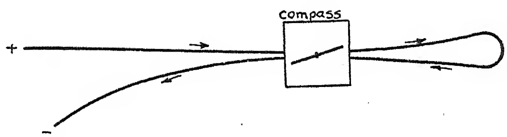


FIG. 26. Equal and opposite flux tends to neutralize.

Experiment 9. A supersensitive compass for these experiments. Materials needed: a No. 6 dry cell; some No. 24 or 26 insulated wire for a magnetizing coil and circuit connections; a heavy darning needle, about 2½ in. long; some thin stiff cardboard; a common pin.

The magnetizing coil used in previous experiments may be used here, or better still, a special coil of about 40 turns may be wound on a paper tube made on a pencil. The tube can be easily made of several layers of writing paper wound on a lead pencil, pasted, and the pencil withdrawn. Do not wind the coil with the paper tube on the pencil, because the pencil may not come out easily.

A short section of straight macaroni also may be used as a winding form for this coil.

Wind two layers on the coil of 20 turns each. Twist the leads several times, to prevent the coil from coming unwound.

Break the point off the darning needle, so the usable section, including the eye, is about 2 inches long. This makes a better pole at the broken end than at a point, and saves pricked fingers.

Insert the needle into the coil. Keep the magnetizing current on for about 10 seconds. Open the circuit, and remove the needle. Be careful not to drop the needle, for dropping any permanent magnet causes a loss of magnetism.

Make a support for the compass needle, as shown in Figure 27, out of a single piece of thin, stiff cardboard. The compass mark-

ings may be made with ink, in a neat design, similar to a mariner's compass points.

Bend a common pin, as shown in the details in Figure 27, to form a hanging needle support. Bend the pin tight enough to fit the needle well. Push the needle into place, and adjust the pin on the needle for perfect balance. Do not injure the pin point; it must be very sharp for best results from the compass.

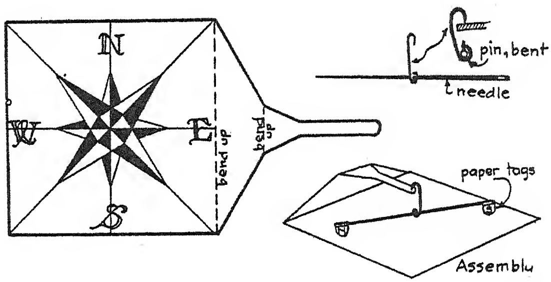


FIG. 27. Details and assembly of special compass.

Hang the needle on the support arm from the base. Do not push the pin point into the cardboard. The sharp pin point resting on the smooth cardboard of the support arm will have little friction and will thus allow the needle to be very accurate in its flux adjustment.

Keep the parts for this compass in a little cardboard box, such as a matchbox, when not in use, to prevent loss or injury. Always adjust the base of this compass so that the needle may swing freely, without bumping the support bracket and pin bearing.

Experiment 10. Internal magnetism. Materials needed: a No. 6 dry cell; the magnetizing coil of Experiment 9; the compass made in Experiment 9; a long, slender needle.

Magnetize the thin needle strongly. About 5 seconds in the coil field will be enough. (Seconds may be counted fairly accurately by saying: one thousand one, one thousand two, etc.)

Try the poles of the needle with the new compass. Do they repel and attract the compass poles properly? Note which end of the needle is *N* and which *S*. Remember, when testing for this, that two *N* poles or two *S* poles repel; and unlike poles attract.

Now break the needle near the middle. Try each end of each part with the compass. How many complete magnets have been made from the original needle magnet? Every magnet must have a pair of poles, *N* and *S*.

Break the pieces again with the use of pliers. Test each end of the four pieces with the compass. How many complete magnets are there now? What does this mean about the inside of any magnet? Are there countless pairs of poles inside a magnet that "appear" when the original magnet is broken?

Try to make a little "chain" out of the broken pieces. Which ends attract? Do any repel? Which? Keep a record of this experiment for reference. Figure 28 suggests a sketch method to show results of such an experiment.

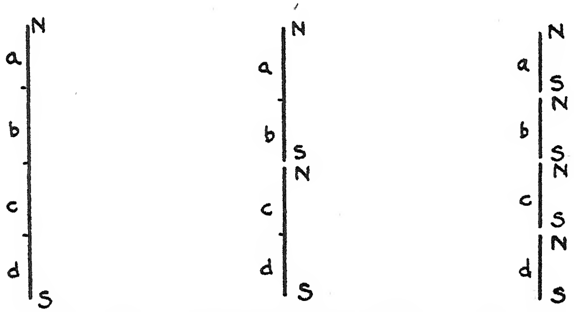


FIG. 28. Poles in broken magnets are always in pairs.

31. **The R.H.R. for a Coil.** In Article 30 was explained the relation of the direction of current in a straight wire to the direction of flux around that wire. A right-hand rule was finally developed to make it easy to remember this relationship. Now, a coil of wire also has flux around it when current is forced through the coil. And a similar rule can be developed to use in all coil problems.

If a straight wire carries current in the direction shown at *A* in Figure 29, then the flux around this wire will be as shown at *A*. Check this carefully with the right-hand rule for flux around a straight wire. Check the flux at *B* by the same rule.

When this same wire is coiled up, as at *C* in Figure 29, then the flux around the wire tends to flow as shown. A cross section of this coil is shown, with enlarged wires, for better detail. The

current coming out of a wire, as at the top of the coil, is always shown as the point of an arrow coming out of the paper. Likewise, the current going into a wire, at the bottom of the coil, is always shown as the tail of an arrow going into the paper. Thus, the wires at the top of the coil are carrying current out of the paper, and the bottom wires carry the current back into the paper again, and up around the back wires of the coil to the top of the coil again.

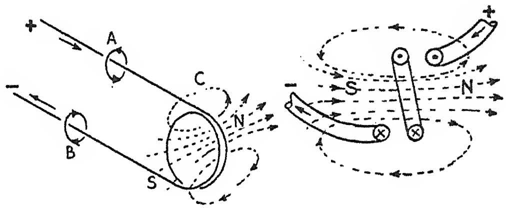


FIG. 29. Flux around a coil carrying a current.

The flux from these coils of wire tends to flow as shown in the coil center. Reversing the current in the coil will reverse the flux. A right-hand rule can be devised to fit all such cases. Using always the right hand, put the

> **Thumb** in the direction of the flux inside the coil, or in the direction of the *N* pole of the coil;
>
> **Fingers** in the direction of the current in the wires of the coil, as shown in Figure 30.

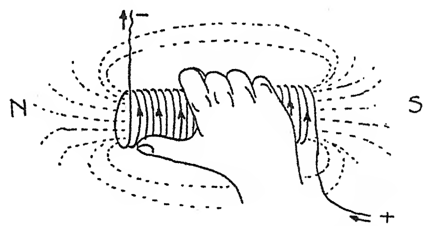


FIG. 30. Right-Hand Rule for a coil carrying current.

Note that it makes no difference which end of the coil the current enters, but only which direction around the coil the current travels, from + to — terminals. Neither does it matter

if all the turns are in one layer or in several layers, just so they are all in the same direction of winding around the coil.

Experiment 11. Testing for the poles of a coil. Materials needed: a No. 6 dry cell; 20 ft. of No. 26 insulated wire; an electromagnet such as previously made; a very sensitive magnetic compass.

Loop the insulated wire into about a 10-turn coil, 4 in. in diameter. Fasten the turns together with string tied around the wire in two places. This coil, when energized from the dry cell, will have two poles, *N* and *S*, the same as all other electromagnets. The flux inside the coil always goes from *S* to *N*. Outside the coil, the flux travels from *N* back to *S*. Examine Figure 31 for these details. Make all connections exactly as shown.

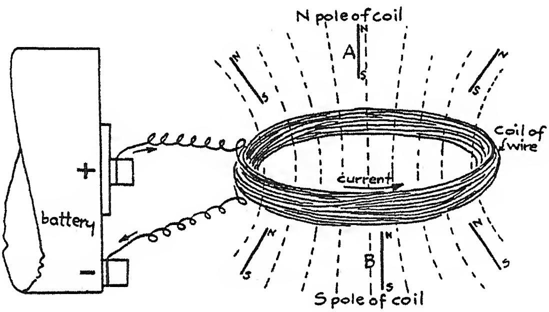


FIG. 31. Flux field around a coil carrying current.

Hold the compass near the coil at *A*. Touch the wire to the +terminal of the battery, to complete the circuit for a second or two. Do not keep the circuit closed longer than this, or the wire will overheat. Note what the compass needle does.

Test pole *B* of the coil. Does this check with Figure 31? Apply the right-hand rule. Try various places in the field to discover the flux direction. Keep a neat sketch of the coil, showing current direction and the flux found to exist around it. Reverse the coil turns, and try the same experiments. Reverse battery connections, and note the effect on the poles. Check with the right-hand rule again. If all cases do not check with the rule, then look over the connections carefully for the error.

The principle brought out in this experiment can be used in an instrument to detect a current flow, and to determine its direction. This device is called a galvanometer.

Experiment 12. Making a galvanometer, or current-flux detecting instrument. Materials needed: some stiff cardboard; a piece of cardboard tube about 4 inches in diameter, such as an oatmeal box; 25 ft. of No. 26 or finer insulated wire; the compass made in Experiment 9; glue or mucilage.

A tube 1 in. long and about 4 in. in diameter may be made from flat cardboard, curled up into a tube. Or one may be cut from a round cardboard box.

Make a 1-in.-wide cardboard shelf and glue it into this tube about ½ in. below the center, as shown in Figure 32. This shelf is to hold the compass, when using the coil and the compass as a galvanometer.

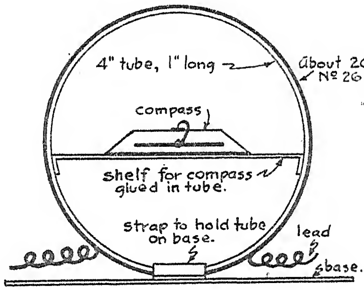


FIG. 32. Details of the galvanometer.

Make a neat cardboard base for the galvanometer, about 2 in. wide by 5 in. long. Also make some kind of strap, of cardboard, to hold the coil form down on the base. A wooden base might be made for the instrument, and two metal binding posts may be used for terminals.

Wind 20 turns of wire upon the tube form. Wind the turns all in one layer, close together in the middle of the tube. Fasten ends of winding through holes near bottom of tube, on each side. Leave leads about 6 in. long for connections to other wires.

Fasten the coil to the base with a narrow strip of cardboard glued down over the tube form, as shown. Make a neat job of these parts, so they show good workmanship.

Set the compass on the shelf provided for it inside the coil. Adjust the assembled galvanometer so that the compass needle rests normally diametrically in the coil; in other words, have the coil axis *E* and *W*, and the coil diameter *N* and *S*.

Send a current through the galvanometer coil. The compass needle will swing according to the direction of flux produced by the current flowing. The right-hand rule can be used to check flux and current directions, or to find one by knowing the other. Try this with very weak currents, and notice how sensitive the galvanometer is in detecting minute currents. Keep the parts for the galvanometer in a cardboard box. The instrument will later be used as a very sensitive device to detect and measure small current in other experiments.

32. Magnets Attract Only Iron. All magnets, either the permanent type or electromagnets, will attract only iron or steel. Such materials as wood, earth, etc., that have iron in them in small percentages, are still not magnetic. The human body has some iron in it, yet is not attracted by a magnet or compass needle.

Experiment 13. Magnetic and nonmagnetic materials. Materials needed: a No. 6 dry cell; a magnetizing coil; a very sensitive compass; samples of wire, paper, wood, glass, asbestos, bakelite, etc., for testing.

Test the samples of wire made of various materials. Bring them near the compass needle. Test such things as a needle, a common pin, a hairpin, a penknife, a silver-table-knife blade, a silver spoon, a silver fork, a strip of cardboard, a roll of tinfoil, copper wire, a piece of clock spring, a strip of tin-can metal.

Keep notes of the results of these tests, listing the material tested and whether the test indicated that the material was magnetic or nonmagnetic. Examine the materials tested. Which are magnetic?

Now try to magnetize the samples. Insert them one at a time into the magnetizing coil, and send current through the coil from the battery. With the current on, test the protruding ends of each test sample for magnetism. Does the coil have magnetic poles without any sample in the core of the coil except air? Then is it a sure proof of magnetic material to test the sample with the current in the coil? Why?

After keeping a sample in the coil field for about 5 seconds, test it outside the coil. Does it have any pole effect? Does this prove it is magnetic or nonmagnetic? Keep a record of the findings of this experiment in a table form such as Table VIII.

TABLE VIII. MAGNETIC CHARACTERISTICS OF MATERIALS

Sample	*Material*	*Before Magnetizing*	*After Magnetizing*
Tin can	iron	none	very weak flux
Nail	steel	none	medium flux
Needle	steel	weak flux	very strong flux
Hairpin	iron	none	very weak flux
Tinfoil	lead	none	none
Pin	brass	none	none
Pencil	carbon	none	none

Try aluminum, if available, in these same tests. Is it magnetic or nonmagnetic? Try gold; solder, etc.

33. Uses for Magnets. Magnets have many commercial and industrial uses. A partial list of the commoner uses of electromagnets is shown in Table IX.

TABLE IX. USES OF ELECTROMAGNETS

Device	*Magnet Use*
Bell, buzzer..............	To attract armature of clapper
Coal cleaners.............	To extract pieces of iron
Motors	Field magnets; armature magnetism
Generator	To create field for armature to cut
Magnetic crane...........	To pick up magnetic materials
Transformer	To create flux in coils
Spark coil................	To create flux in secondary coil

Many other uses are possible, which would add dozens of items to Table IX, but the ones mentioned are common. No doubt the doorbell or buzzer is the commonest one of all. A buzzer can easily be made from materials around most workbenches.

34. Construction of a Buzzer. The principle of a buzzer is simply that of an electromagnet attracting an iron armature. A contactor is so arranged that, when the iron armature moves in toward the magnet, the contacts are opened in the electro-

magnet coil circuit. The flux dies out, and then the armature springs back away from the magnet. This closes the contacts, and the action repeats, making the armature vibrate or buzz.

A clapper attached to the iron may be made to strike a bell, as in the common doorbell used in homes for signals. Examine a bell or buzzer. Note what kinds of materials are used for the various parts of the device.

Experiment 14. Making a simple buzzer. Materials needed: a soft iron bolt, flat square head, ⅛-in. diameter shank, about 1¼ in. long, with nut; some tin from a discarded tin can; about 25 ft. of No. 26 insulated wire; stiff cardboard; 5 small screws.

Make two coil ends of cardboard, about ¾ in. in diameter, to fit the bolt shank. Wrap paper on the bare bolt shank, to insulate it from the magnet coils. Wind on about 150 turns of the No. 26 magnet wire. Arrange for about 6-in. leads on the winding. Cover the completed electromagnet with heavy paper to protect windings.

Make a wooden base for the buzzer, out of smooth soft wood, about 2½ in. square and ½ in. thick. The edges should all be smooth and straight.

Make the strap *S*, armature *A*, and contactor *C* out of clean, bright tin. Tin is really soft iron covered with a tin coating. Cut these pieces out of flat tin, such as the side of a can that has been flattened out nicely. Smooth all edges with a file. Drill holes as indicated in Figure 33, and bend where shown by dotted lines.

Attach all these parts to the wooden base with small screws. Nails will do, if screws cannot be had. Make the connection shown at *X*, between one coil lead and the armature, by placing the bare wire end under the tin before it is screwed down tight. Also connect a lead to the contactor *C*, before fastening *C* in place on the base. Two brass binding posts may be added, if desired.

This buzzer will operate nicely on a single dry cell. The contactor point should just touch the armature lightly when no current is in the buzzer circuit. Adjust the armature or contactor slightly to get the most satisfactory operation of the buzzer.

35. Circuit Breakers and Their Uses. Fuses have one outstanding disadvantage. Every time a fuse "blows out," a new fuse must be put in place.

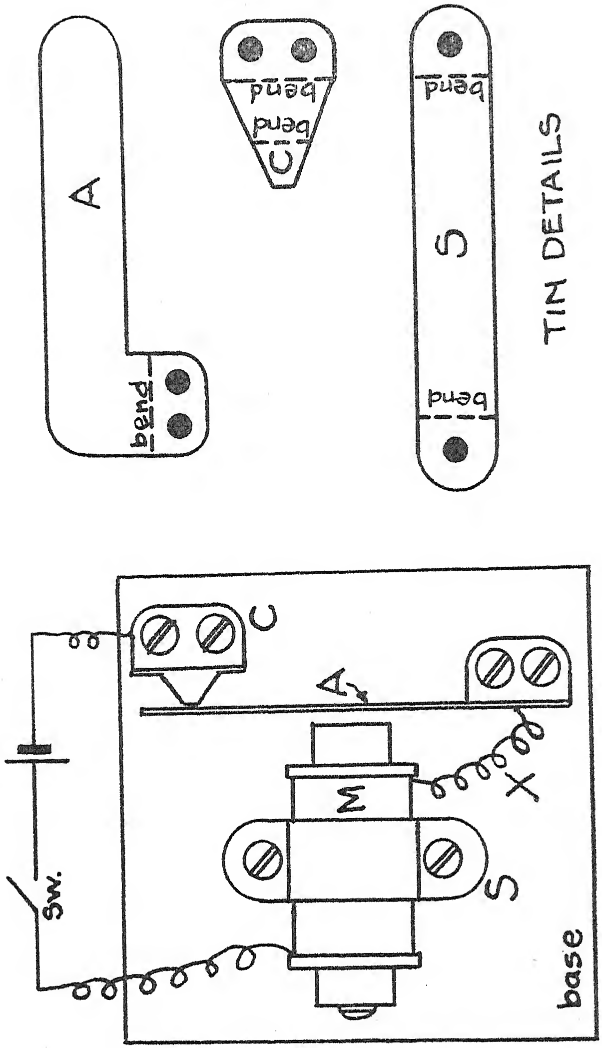


FIG. 33. A simple electric buzzer.

What is needed in such cases is some kind of automatic switch that will trip open when an overload occurs, and can be closed in again by hand, after the fault on the line has been corrected.

Such a device usually is called a **circuit breaker.** A circuit breaker is merely a switch held in the closed position by a latch that releases the switch blade when the current gets too high. A simple electromagnet arrangement is connected in the main line, to do this, as shown in the scheme diagramed in Figure 34.

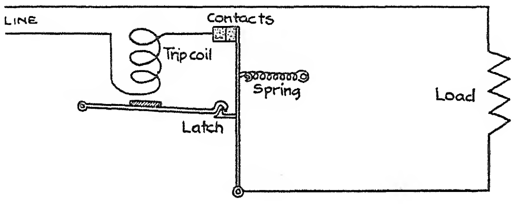


FIG. 34. Schematic diagram of a circuit breaker.

When the current to the load becomes too high for safety, the trip coil becomes strong enough to lift the latch, and the switch contacts open. The circuit breaker may be closed in again by hand. The latch automatically catches the hook on the switch arm and holds it closed, against the spring tension, until the next overload on the line causes it to open again.

With a little ingenuity, the buzzer made in Experiment 14 may be reconstructed into a simple circuit breaker. The armature of the buzzer may be used as the latch of the circuit breaker, by bending the end over slightly to form a hook to engage the switch-arm catch.

Large circuit breakers are usually enclosed in tanks filled with a good grade of oil, to extinguish any arc at the contactors when they break the heavy current of an overload. Power companies often use circuit breakers that not only automatically open on overload, but close in again automatically. Some of these special circuit breakers are capable of operating in less than 1/25th of a second. Thus they can open the circuit long before serious damage is caused by the heavy current.

36. **Static Electricity.** The latest scientific researches in electrical laboratories lead scientists to believe more firmly

then ever that all materials are made of electrons. Our scientists now believe that materials differ only in the way the electrons which compose them are arranged; that is, how the electrons are spaced or built up. The same units may be made up into much different things, similarly to a penknife and a watch both being made from the same materials.

When electrons move, or flow in a stream in a wire, at a rate of x coulombs per second, the current is said to be x amperes in that wire.

However, a wire has electrons even when no current flows. Such stationary electrons are called **static charges.** These charges of electrons are **negative** charges.

Positive charges also exist in the same manner as negative electron charges. These positive particles are called **Protons,** to agree with the name *electron.*

These special + and — charges can be separated and collected in interesting manners that show up many details about their characteristics.

37. Generating Static Charges. When two unlike materials, such as a rubber comb and hair, are rapidly rubbed together, static charges appear on the materials. Sometimes enough static is generated by a dry belt whirling swiftly over pulleys, that long sparks can be drawn from the belt to a workman's hand. Such belts have been known by their sparks to cause very bad explosions in flour mills. In powder factories, belts must all be enclosed in metal shields, to prevent static sparks.

It is interesting to generate small + or — charges, and study their characteristics, first hand.

Experiment 15. Generating a negative charge. Materials needed: a rubber comb; a piece of fur (catskin, or hair on the head will do) or a piece of flannel; some small pieces of tissue paper, ⅛ in. square; a piece of thin, dry, silk thread; a dry, clean cork, cut into tiny ⅛-in. cubes.

Rub the hard rubber comb rapidly with the fur or flannel. The comb will become covered with unbalanced — charges, or electrons. (Remember that electrons are negative.)

Touch the — charged comb to the ear. Does a tiny spark jump? Can it be heard? Try the comb near the nose. Just before the comb discharges to the nose, a slight crackling noise can be heard, caused by the charge slowly **leaking** off the comb.

Bring the — charged end of the rubber near small pieces of paper or cork. What happens? This is **not** caused by a magnetic field, but by an **electrostatic** field around a charged surface. How far away from ⅛-in. square bits of tissue paper will the field of the charged comb act on the paper? Does the field get weaker further from the comb? How does this compare to a magnetic field, in this respect?

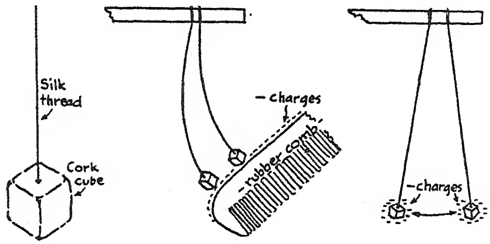


FIG. 35. Effects of a negative charge.

Will the charged rubber attract bits of cork? Do the cork cubes remain attached to the comb indefinitely? When they take on part of the charge of electrons (—) of the rubber, and are then like charge to the rubber, do they fly off the rubber? Why?

With a needle or a pin, push or thread a piece of silk thread in two small cork cubes, as shown in Figure 35. Hang the pieces of cork from some support. Bring the electrified or charged rubber near the cork cubes. What happens?

What can now be said for the likeness of static fields and magnetic fields?

Try a metal rod, rubbed with the fur or flannel. Does a static charge show itself, when treated as in the case of the rubber? Do conductors retain a static charge? (No. The charge is generated, but can flow away, along the metal. In insulators, the charge cannot flow. Note that the charged hard rubber must be discharged all along its surface, to completely discharge it.)

Discharge the cork cubes by touching them with a wire or the fingers. Do they still repel? Why? Recharge them from the comb and note that they again repel. What law appears to exist for like charges? For unlike charges?

Experiment 16. Generating a positive charge. Materials needed: a glass rod; a piece of dry silk; the cork cubes used in Experiment 15; bits of tissue paper.

A positive charge will appear on the glass rod, when the rod is vigorously rubbed with the dry silk which will be negative.

Perform the same tests as in Experiment 15. All results should verify the law for static fields that:

Like charges *repel; unlike* charges *attract.*

38. Electroplating. The modern commercial and industrial world is crowded with uses of electroplated metals. These include many things in common use by most everyone, every day, some of which are shown in Table X.

TABLE X. ELECTROPLATING USES

Plating	*Some Uses*
Copper	Carbon brushes; under nickel and chromium
Brass	Hardware; tools, to prevent rust
Nickel	Hardware; ornaments; tools
Chromium	Automobile parts, etc.
Cadmium	Instruments; surgical knives, etc.
Silver	Dinnerware; jewelry; instruments
Gold	Very fine instruments; jewelry, etc.

The electroplating process is simple to understand. It uses current to deposit a layer or film of the desired metal on some object. The object to be plated must be clean and bright or the plating will not adhere well to its surface.

Electroplating has been developed into an art in itself. The baser metals, such as iron, steel, copper, and brass, can all be used for expensive parts, when properly plated with silver or gold. For example, automobile bumper bars are pressed out of hard steel, and are chromium plated to give a weather-resisting surface. Table knives, with the blades made of necessarily hard steel to withstand the wear, have brass handles, cast onto the blades. The whole knife is then silver plated, to provide a beautiful surface that is smooth and easy to keep sterile.

39. Method of Electroplating. The details of all kinds of

electroplating are similar. They may be easily summed up in table form.

1. Metal to be plated must be clean and bright.
2. Metal to be plated must be connected to the — line.
3. The plating solution must be a salt of plating metal. For example: Silver nitrate is used in a silver-plating tank, copper sulphate in a copperplating tank, etc.
4. A rod or plate of the same metal as the desired plating must be placed in the tank, attached to the + line.

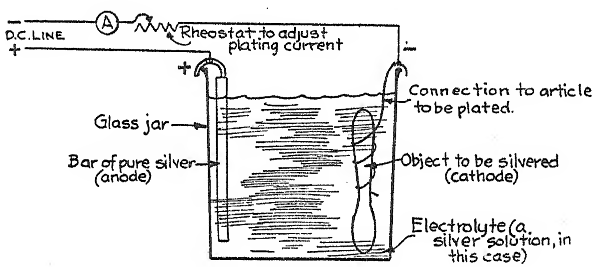


FIG. 36. Silver-plating process.

Figure 36 shows a diagram of a silver-plating tank. A rheostat generally is used to regulate the current so an even plate is produced. Such a setup as this is used to silver plate reflectors for automobile headlamps. When the plate has been built up to the desired smooth heavy surface, it is buffed and polished by a motor-driven polisher. When properly done, such electroplating will never loosen from the base metal under it.

Experiment 17. Copperplating. Objects may be copperplated in a manner similar to the scheme shown in Figure 36. The metal surface to be copperplated must be absolutely clean and bright, or the plating will be very poor and very uneven. Observe these rules:

1. The anode (+) must be a bright piece of copper sheet.
2. The solution (electrolyte) should be copper sulphate.
3. The tank must be a nonconductor, such as glass.
4. The d.c. voltage should be about 6 volts; a.c. from a transformer will not do the job.
5. The plated surface must be polished after plating.

40. Electrolysis of Water. It is possible to break down

water into its parts of hydrogen and oxygen, by passing current through the water, between two plates or electrodes.

The hydrogen in the water acts as if it were a metal in the solution of an electroplating tank. The hydrogen will appear in bubbles at the — plate in the water. The oxygen that is left gathers in bubbles at the +plate in the water.

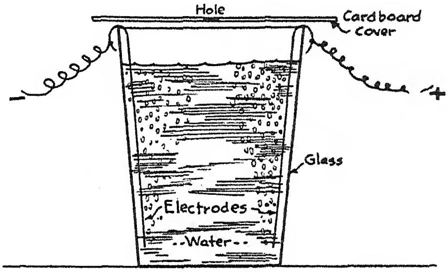


FIG. 37. Electrolysis of water.

Experiment 18. Decomposing water by electricity. Materials needed: a d.c. source of at least 10-volts pressure; some bright tin or copper strips; some insulated wire; a glass jar or water glass; a little sulfuric acid (poison — see Art. 62).

Fill the glass with water. Add 5 drops of sulfuric acid to make the water a good conductor or electrolyte.

Cut two clean metal strips, about ½ in. wide and 4 in. long, for electrodes. Tin strips from a discarded tin can will serve, if no sheet copper is available. Bend these strips to hang over the edge of the glass, down into the water. Be sure the strips do not touch at any point.

Make contact, for a few seconds, on these strips, with wires from the direct-current source. Figure 37 shows details of all this.

What happens near each electrode? Smell the rising gases. What kind of an odor have they? Cover the glass with a piece of cardboard with a ¼-in. hole in the middle. When gas accumulates under the cardboard lid and begins to come through the hole, hold a lighted match near the hole. (A slight explosion will occur, so exercise care in doing this.)

Which electrode or plate (+ or —) has the most bubbles on it, when current flows? Note that water is made up of 2 molecules of hydrogen for every 1 molecule of oxygen (H_2O).

Does reversing the current make any change in the effects noticed before? What?

Experiment 19. Same as Experiment 18, but using an a.c. supply. Additional material needed: a 40-watt lamp and lamp socket; a 110-v. a.c. power source.

Connect the parts as indicated in Figure 38, with the 40-watt lamp in series with the electrolysis cell. This will prevent burning out the line or a fuse, in case of an accidental short.

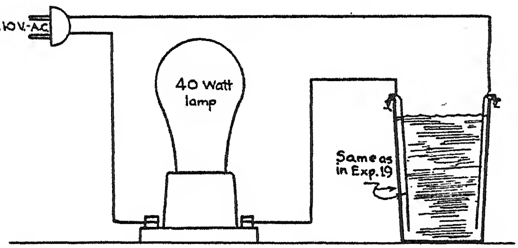


FIG. 38. Effect of a.c. on water.

Do the same amount of bubbles form on both electrodes? Why? Are the hydrogen and oxygen bubbles equally mixed on both plates? (Remember that an alternating current reverses its direction at regular intervals, usually 60 times a second.)

Does adding more acid to the water increase the action? Try it and see.

Does the lamp burn brighter when the electrodes are closer in the solution? Why? Does Ohm's law apply here? Why does the water get warm?

Experiment 20. Making hydrogen and oxygen. Materials needed: two metal electrodes; a large glass tray or dish; two small long bottles; some rubber-insulated wire; sulfuric acid; a d.c. source of 15 or 20 volts.

Arrange the glass dish and bottles as shown in Figure 39, so the gas liberated at each electrode will be collected in the bottles over the electrodes.

Add about 10 drops of acid to the water. Then fill the bottles under water and stand them up, with mouths always under water. Outside air pressure will keep the water up in the bottles.

Rubber insulated leads must be used, and must not be bare

until they are up inside each bottle, attached to the electrodes.

Twice as much hydrogen as oxygen will form because water is H_2O; this means 2 hydrogen atoms for every oxygen atom.

Turn off the current when some gas has been collected above each electrode. Remove bottle *A* from the water, keep the mouth downwards, and hold a glowing match up into it. Note how much better the match burns (because of more oxygen).

Remove bottle B, mouth downward. Carefully bring the mouth of the bottle near a flame, and tip the bottle to let the hydrogen escape. A slight explosion may occur, with a light-blue flame, as the hydrogen burns.

This is a common electrolytic method for making hydrogen and oxygen for commercial use. The method is cheap and efficient.

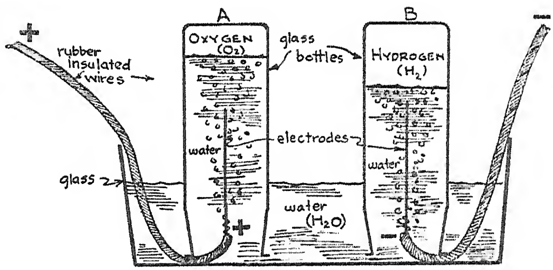


FIG. 39. Making hydrogen and oxygen electrolytically.

SUMMARY

Current in a conductor may cause heat. This heat may be useful or dangerous. Resistance wires get hot when carrying current.

Fuses are used to protect lines or equipment from overload.

Current in a wire produces a magnetic field around that wire.

Iron-cored electromagnets have greater magnetic strength than air-cored electromagnets, on the same current.

Iron and steel are magnetic materials. Steel is used for permanent magnets, soft iron for electromagnets.

Law of magnetic poles, always in force:

Like poles repel.

Unlike poles attract.

More current and more turns on an electromagnet produce a stronger flux.

Right-Hand Rules:

For a straight-wire carrying current:

Thumb in direction of current in wire.

Fingers around wire in direction of flux around wire.

For a coil carrying current:

Thumb in direction of flux inside of coil; points to N of coil.

Fingers around coil in direction of current in wires.

Law of Static Charges:

Like charges repel.

Unlike charges attract.

PROBLEMS

Prob. 1. An electric hotplate has a resistance of 10 ohms. How much current will it consume on a 115-volt line?

Prob. 2. Which should have the largest copper wire for a line: a 3-ohm resistance on 120 volts, or a 7-ohm resistance on 245 volts?

Prob. 3. Which resistor will reach the highest temperature on a 100-volt line: 16 ohms, 30 ohms, or 45 ohms?

Prob. 4. Thirty 60-watt lights are paralleled for stage lighting. Find the total current drawn by the string on a 120-volt line.

Prob. 5. About how many 60-watt lamps can be operated on a 120-volt line with the same current as a standard household electric iron?

Prob. 6. A 24-ohm heater and four 60-watt lamps are operated in parallel on a 120-volt line. Find the total line current.

Prob. 7. A 10-volt, 5-ohm lamp is to be lighted on a 60-volt line. Find the correct value of ohms for the necessary series resistor.

Prob. 8. Find the approximate fuse rating for a circuit of sixteen 60-watt lamps in parallel, all lighted at the same time, on a 120-volt line.

Prob. 9. A rubber-insulated No. 14 wire should not be made to carry over 15 amperes. Find out if this wire is safe to use for short leads to deliver power to a 50-ohm load on a 115-volt line.

Prob. 10. Diagram the best placement of separate fuses to protect a ½-horsepower motor and eight 60-watt lamps on a 120-volt line. Find the approximate fuse rating for each place.

Prob. 11. Why should the safety switch be opened before a fuse is removed or changed?

Prob. 12. Why should the lines be checked for the possible fault before a new fuse is put in place and the power is connected?

Prob. 13. Why are cheap fuses with questionable "ratings" a poor economy? What is the danger in using metal slugs as "substitutes" for house line fuses?

Prob. 14. Suppose a 110-volt line is fused for 30 amperes. Find out if the fuses will "carry" a 10-ohm load.

Prob. 15. Diagram a good method to permanently magnetize the steel head of a small tack hammer, so it will hold a tack ready to drive with a blow. Does it make any difference whether the hammer head becomes *N* or *S?*

Prob. 16. If half the turns are removed from an electromagnet, how much must the new current be increased to have the same flux?

Prob. 17. How can the *N* end of a compass be checked by the sun?

Prob. 18. Would a magnetic compass register correctly in an airplane? Why does the needle turn toward unmagnetized iron very near it?

Prob. 19. If two poles strongly repel, does this absolutely prove they are both *N* poles? Explain.

Prob. 20. What condition in a piece of iron in a motor armature will make the *N*-field pole attract it with the greatest force? Repel it with the greatest force?

Prob. 21. Compare the relative strength of these two electromagnets: No. 1 has 60 turns that carry 10 amperes; No. 2 has 120 turns that carry 5 amperes; both cores and other construction details are the same.

Prob. 22. Show a horizontal wire, with current passing through it from left to right. Show the flux direction around this wire. What effect will doubling the current have on the flux?

Prob. 23. Where both + and — wires of a circuit are enclosed in the same iron pipe, will the pipe become magnetized? Will the amount of current affect this any?

Prob. 24. If two + wires are enclosed in one pipe and two — wires in another pipe or conduit, will these circuits magnetize the pipes? Why?

Prob. 25. How could brass-plated iron hardware be surely recognized as not of solid brass, without marring the hardware in any way?

Prob. 26. Will a steel-wire carrying current become magnetized? How? Why?

Prob. 27. If a magnet attracts only iron objects, explain how a tin can is attracted by a magnet.

Prob. 28. What kind of material in the earth permits it to remain for countless ages a strong permanent magnet? Does the removal of iron ore by man decrease this magnetism?

Prob. 29. Show the earth as a globe. Indicate how a compass needle will point at various places around this globe. How will a compass tend to point at the *N* pole? At the *S* pole?

Prob. 30. Show by a sketch how to compare the relative magnetic strength of two poles with tiny nails, tacks, or iron filings.

Prob. 31. It is known that like magnetic lines of flux repel each other. How will the flux of two *N* poles held ½ in. apart be? Explain with a sketch, showing the flux pattern in the gap.

Prob. 32. Show a winding diagram for a U-shaped electromagnet, having a winding on each pole end. Be sure to check the flow of current around the magnet with the *N* or flux desired.

Prob. 33. If one of the coils in Problem 31 is reversed, so the current flows around the magnet the other way, what effects will be noticed?

Prob. 34. How can a bell or buzzer be adjusted to ring or vibrate more rapidly?

Prob. 35. Does the contactor sparking harm the contact points on a bell or buzzer? What causes this arcing?

Prob. 36. When a rubber rod is rubbed with fur, why do the rod and fur attract each other?

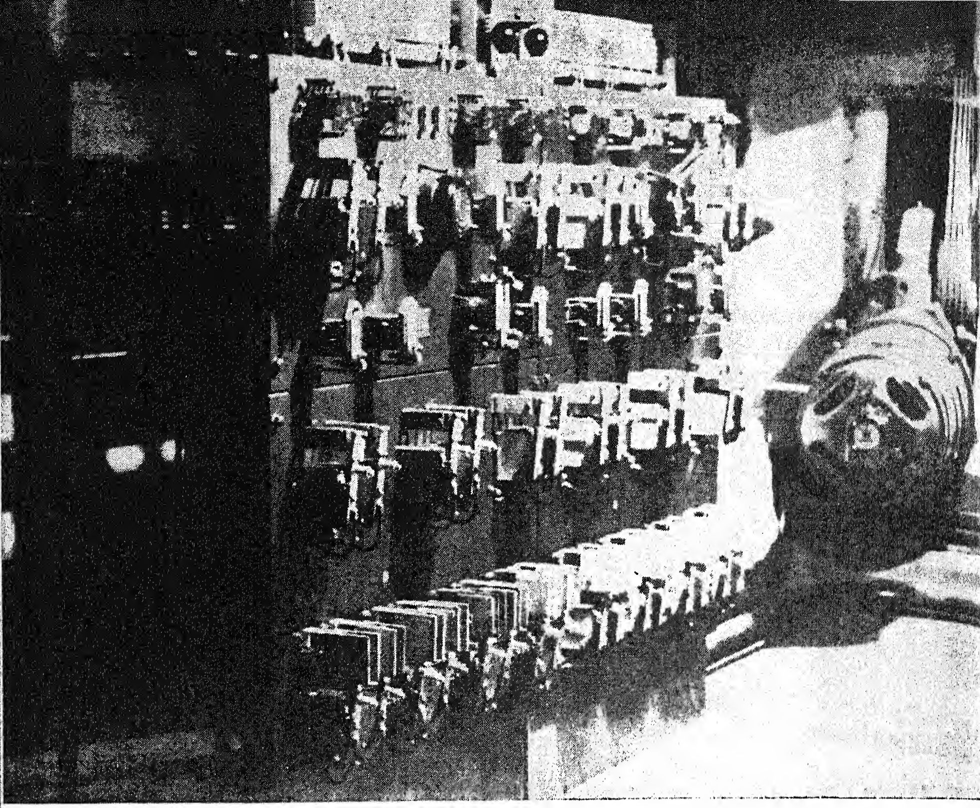
Prob. 37. Compare the laws for magnetic poles and for static charges. Explain how to generate a — charge; a + charge.

Prob. 38. Diagram an electroplating cell. To which battery terminal must the metal to be plated be connected? Why?

Prob. 39. For what reasons must street-car rails be "bonded" with heavy copper cables at rail joints?

Prob. 40. How can the corrosion on storage-battery terminals be overcome? What is corrosion?

Prob. 41. Why should battery connections always be firmly made? Give two reasons.



AN ELECTRIC BRAIN FOR A MOTOR

Modern high-speed elevators that stop automatically at the exact floor level require high-speed, automatic-control equipment. Relays, resistance banks, and special circuit breakers make up these panels which control the motor speed, its direction, and its dynamic brake. The hurried passenger seldom sees these marvelous electrical mechanisms, but they are always on duty to serve and protect him in his swift, smooth ride up or down the shaft.

Chapter III

RESISTANCE: CROWDING THE ELECTRONS

ELECTRICAL resistance is another term for the friction of a material to the flow of current through it. The electrons may be looked upon as having actual size, and needing a certain amount of room or space in a wire in which to flow. Lacking the necessary space, a conductor is said to have a high resistance to the flow of current. Low resistance might mean that there is enough space between the particles of the conductor so that electrons may pass through it quite freely. Resistance is always measured in units of ohms, as was discussed previously in Chapter I.

To force current through a high resistance, a much higher voltage than normal is needed. Of course, such a forced current will generate heat in the conducting material. Sometimes such heat is useful; other times it is a danger and disadvantage. A toaster utilizes electric heating, but a motor, when too hot, may be seriously damaged.

42. **Common Resistances.** Some common values of resistance will help to make the unit of ohms seem more real. All materials have resistance, whether carrying current or not. The lead in a lead pencil has a certain resistance in units of ohms as one of its definite characteristics. That resistance does not change, if the lead is not cut, or shortened, or changed in any way. In the same sense, Table XI shows the average resistance values that some common electrical devices have.

43. **Ways to Measure Resistance.** The resistance of any device may be measured by several methods. The easiest method usually is to measure the current delivered to the device and the voltage drop across it at that current. Then the resistance (R) of the device may be found by dividing the voltmeter reading (E) by the ammeter reading (I). This ammeter-voltmeter

method is shown in diagram form in Figure 42, where *X* is the unknown resistance.

TABLE XI. COMMON RESISTANCE VALUES

	Ohms
Ammeters, well-made, precision instruments	.01
Copper wire, 1000 ft. No. 10 B. & S. gauge	1.0
Copper wire, 1000 ft. No. 14 B. & S. gauge	2.5
Copper wire, 1000 ft. No. 18 B. & S. gauge	6.4
Copper wire, 1000 ft. No. 24 B. & S. gauge	25.7
Copper wire, 1 ft. No. 40 B. & S. gauge	1.1
Electric iron, 550-watt, 110-volt	22.0
Electric light, 60-watt Mazda, 120-volt	240.0
Voltmeters, well-made, precision instruments (100 ohms per volt of scale)	
150-volt range	15,000.0
300-volt range	30,000.0

An ohmmeter also can be used to measure resistance. This instrument looks somewhat like a standard voltmeter, in a case, with two long leads with which to connect to the resistance to be measured. Several styles of case for the ohmmeter are used, but the operation of the instrument is always the same. The resistance measured is read on a dial, over which a pointer moves as in other meters. Figure 43 shows this scheme in use to measure the resistance of *X*.

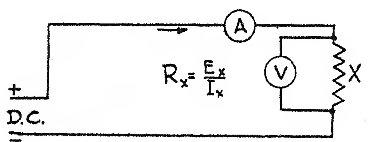


FIG. 42. Ammeter-voltmeter method of measuring resistance.

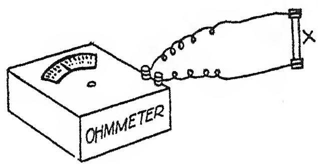


FIG. 43. Ohmmeter, used to measure resistance.

An ohmmeter has a small battery within the case of the instrument, to supply the current to operate the meter. The meter itself is merely a special voltmeter-type instrument, with a scale of ohms instead of volts.

Another method of measuring resistance is called the Wheatstone Bridge Method. This method is only used in special cases of resistance measurements, and so will not be discussed here in detail. You can look it up in an advanced text.

44. Insulators Are Really Just Poor Conductors. Even the best of insulation is not perfect. Its resistance may be very high, and thus allow very little current to leak through it. Thus it would seem to be a good insulator at normal or ordinary voltages. But at higher voltages, the current might be enough to warrant calling the same material a high resistance or a poor conductor, instead of an insulator. This is shown in Table I, where various materials are compared as insulators and conductors. In general, conductors have low resistances, and insulators have extremely high resistances.

45. Resistance Materials Compared to Copper. The common conducting materials, compared to copper, all have higher resistance values than pure copper. But sometimes other metals, such as steel, iron, aluminum, and brass, are used rather than copper, for reasons of mechanical strength or costs involved. Examples of this are the steel rails of street-car tracks. Copper rails would be better conductors for the current from the car back to the power station; but copper rails would not withstand the wear of traffic very well. The same applies to the steel car wheels.

Power companies use aluminum wire for many high-voltage lines, because aluminum wire is very light yet very strong. Such aluminum wires must be of a larger size than copper, to carry the same current, because the resistance of aluminum is greater than that of copper wire of the same size.

Table XII gives a list of metals commonly used as conductors and resistors in electrical work, and some interesting data about these metals. Many interesting comparisons may be made from an examination of this table. **Note that a mil-foot means .001 inch in diameter and 1 foot long.**

Note the very high resistance of lead, 12.13 times as much as copper. The reason lead is used for storage-battery terminals is because it can resist the action of the battery acid well, and will not corrode as would copper terminals.

Table XII may be used to find the resistance of any kind of wire listed, when the resistance of a similar sized copper wire

TABLE XII. COPPER COMPARED TO OTHER METALS

Metal	*Lbs. per Cu. In.*	*Ohms Resistance per Mil-foot*	*Resistance Compared to Same Size Copper*
Copper	.320	10.4	1.00
Silver	.379	10.5	1.01
Aluminum	.096	18.2	1.75
Zinc	.255	36.6	3.52
Brass	.303	45.0	4.33
Iron	.278	74.0	7.12
Solder	.340	112.0	10.77
Steel	.283	118.0	11.35
Lead	.411	126.1	12.13
Nichrome	.306	605.0	58.17

is known. For example, suppose a copper-wire telephone line, having 165-ohms resistance, is to be replaced with iron wire of the same size. How will this change affect the resistance of the line?

1. The iron wire will have 7.12 times as much resistance as the copper line of the same size. The new line will thus have about (165)(7.12) or 1175.8 ohms resistance with the iron wire in place of the copper wire.

2. The voltage drop caused by this increased resistance will be about 7.12 times as great as for the copper line. If the drop on the copper line was 10 volts, the new iron line will have a drop of 71.2 volts (10×7.12) when carrying the same current as the copper line did.

3. The same operating voltage as used on the copper line will drive only $\frac{1}{7.12}$ or about .14 as much current through the new iron circuit as in the copper circuit. In other words, to deliver the same current in the new high-resistance iron line as was in the old copper line, 7.12 times as much voltage must be applied to the line.

Carry out these same ideas, using a new aluminum line to replace the old copper line. Note that to carry the same current as the copper line, at the same voltage, the aluminum wire must have 1.75 times as much cross-section area as the copper wire.

To have the same current-carrying capacity as the copper trolley wire, the steel rails of a street-car system must have at least 11.35 times as much cross-section area as the wire. Of course, the ordinary rails have much more area than this minimum amount, and so they do not offer as much resistance to the flow of current as does the trolley wire.

TABLE XIII. COPPER-WIRE TABLE

B. & S. Gauge	*Diameter in Inches*	*Cross Section in Sq. Inches*	*Ohms per 1000 Ft.*	*Allowable Amperes*
0	.325	.833	.098	150
2	.258	.523	.156	110
4	.204	.328	.249	85
6	.162	.207	.395	60
8	.129	.130	.628	40
10	.102	.082	.999	30
12	.081	.052	1.59	25
14	.064	.032	2.53	18
16	.051	.020	4.02	12
18	.040	.013	6.39	8
20	.032	.008,0	10.2	5
22	.025	.005,1	16.1	3
24	.020	.003,2	25.7	2
26	.016	.002,0	40.8	1
28	.013	.001,0	64.9	
30	.010	.000,80	103.	
32	.008	.000,50	164.	
34	.006	.000,31	261.	
36	.005	.000,20	415.	
38	.004	.000,12	660.	
40	.003	.000,07	1,050.	

46. How Wire Size Affects Resistance. The diameter of a wire makes a difference in the resistance of the wire. The larger the diameter, the less resistance in a given wire. The smaller the wire, in diameter or cross-section area, the more resistance it will have. This is easy to understand by comparing the wire to a water pipe. The larger the pipe, and the larger the cross section of the hole through it, the easier for water to flow through it, and thus the less resistance the pipe has. The same rule applies to the electric wire.

Table XIII shows how rapidly the resistance rises as the wire diameter (inches) and the cross-section area (square inches) decrease. Notice that 1,000 ft. of No. 10 gauge copper wire has about the same resistance as one foot of No. 40 gauge copper wire. But notice that 10-gauge wire is about 1/10 in. in diameter, while 40-gauge wire is only 3/1000 in. in diameter.

The longer a wire is, the more resistance it has. The shorter the wire, the less resistance it has. This, too, is just a matter of common sense. Table XIII shows the resistance of copper wire per 1,000 ft. of length.

This table was compiled from data given in *Circular 31* issued by the U. S. Bureau of Standards at Washington. The table shows the properties of annealed copper wire at room temperature 68 deg. F.

Table XIII is very useful in determining the size of wire to use for any job. The even sizes of wire listed are the common ones in use. Wire may be obtained in much larger sizes than No. 0, such as No. 00, No. 000, etc., but this is used only on very heavy current equipment. Finer sizes than No. 40 also may be obtained for very special work in instruments or laboratory uses, but these are not common.

Suppose, for example, we want to find out how much resistance 40 ft. of No. 18 wire will have, and the voltage drop of this line at maximum allowable current.

Well, Table XIII shows that No. 18 copper wire has 6.39 ohms per 1,000 ft. Therefore, 40 ft. will have 40/1000 of 6.39 or $(.040)(6.39) = .2556$ ohms.

The current allowable for a No. 18 wire is, according to Table XIII, 8 amperes.

Thus the drop in the line at 8 amperes will be $E = IR$, or $E = (8)(.2556)$, or 2.04 volts. At smaller current than 8 amperes, the line drop will be less, of course. Similarly, other practical problems are easily solved by use of the wire table. If iron wire, or steel wire, etc., is used, then the data of Table XII must also be used to find the resistance desired.

For example, suppose the resistance of 50 ft. of No. 26 iron wire is to be found. First refer to the copper-wire table, where No. 26 copper is seen to have 40.8 ohms per 1,000 ft. Therefore, 50 ft. of No. 26 will have only 50/1000 of 40.8, or $(.050)(40.8) = 2.04$ ohms.

But Table XII shows that iron wire has 7.12 times as much resistance as copper. Therefore, the 50 ft. of iron wire, No. 26, will have a total resistance of (7.12)(2.04) or 14.52 ohms.

The allowable current-carrying capacity of this iron wire will be 1/7.12 of the current-carrying capacity of copper wire, or $(1 \div 7.12)(1) = .14$ amp. More current than this value will greatly overheat the wire. (No. 26 copper can carry 1 amp.)

47. Construction of an Electric Furnace. Resistance always causes a heating effect, when much current is forced through a circuit. This heating effect may be put to use in an electric oven or an electric furnace.

Suitable resistance material for such devices may be purchased at about ten or twenty cents, the price of 16 to 18 ft. of No. 22 B. & S. gauge **nichrome** resistance wire. The ten-cent stores usually stock replacement resistance coils for the reflector- or radiant-type electric room heaters. This wire may be used in the coiled-up length as it comes, or it may be stretched out straight and wound as desired.

Proper insulation for a stove or furnace may be had by using plenty of asbestos paper, such as is used to cover house heating pipes. Asbestos board may also be used to support the heating wires safely.

Experiment 22. Making a small electric furnace. Materials needed: a piece of 1-in. pipe, about 6 inches long; 3 ft. of asbestos paper, 6 in. wide; 16 ft. No. 22 gauge nichrome resistance wire; a mounting board; two brackets or metal strap supports, screws, heavy flexible lead and plug for use on 110-v. a.c. supply line.

These materials may be made into a very simple electric furnace, in which to heat a small soldering copper quickly and conveniently.

On the piece of pipe, wind about 4 layers of the asbestos paper for safe insulation of the heating element from the pipe metal.

Upon this paper, wind the 16 ft. of No. 22 nichrome resistance wire in evenly spaced turns. This winding can be in one layer, if care is used to space the turns about 10 to the inch, for about 4¾ in. These details are indicated in Figure 44.

Short leads are left on each end of the nichrome wire to provide for bolted connections to heavy copper wires.

Cover the entire winding with 7 or 8 layers of the asbestos paper. Supports of iron or brass strap may now be arranged to

hold the furnace about 1½ in. above a wooden base, as shown in Figure 44. A fuse block and switch should also be mounted on this same baseboard, to provide safe operation of the furnace on 110-v. a.c. The fuse link should have about a 10-ampere rating.

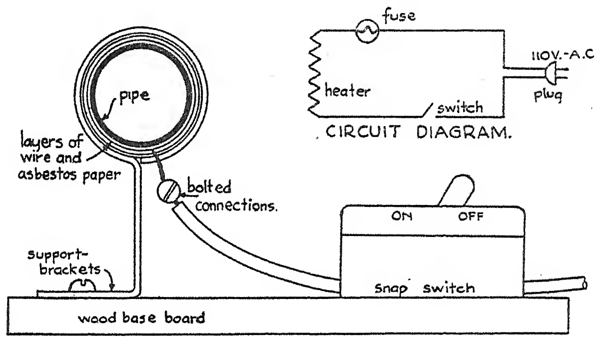


FIG. 44. A simple electric furnace.

Such a furnace will come rapidly to operating temperature and hold the heat very well. Part of the heat is caused by the induced current in the iron pipe, as in a transformer secondary coil when the primary is excited from an alternating-current line.

Similarly, electric stoves, melting pots, etc., may be made. Transite board, asbestos board, and asbestos paper are the most useful insulating and supporting materials in such devices.

48. Series Resistances. Whenever two or more resistances are connected in series, certain facts exist about the entire circuit.

1. The maximum allowable current in the circuit is the smallest allowable current in any one part of the series circuit. If this part can stand only up to 2 amperes, for example, then that current (2 amps.) is the maximum allowable current for the circuit, even though some other part of it may be able to stand 60 amperes safely.

2. The current throughout the entire circuit will be the same in all parts. (This was discussed thoroughly in Art. 12, Chap. I.)

3. The total resistance of a series circuit is equal to the sum of all the various resistances in series (see Chapter I).

4. The total voltage on the whole circuit is equal to the sum of all the "IR drops" of the various parts (see Chapter I).

These statements are applications of Ohm's law to the case of a series circuit.

Street arc lights and Christmas-tree lights are two common examples of series resistances.

49. Parallel Resistances. Household power and light services are usually parallel circuits, as discussed previously in Article 14, Chapter I. The law or rules of parallel circuits of resistances are given in Articles 15 and 16, but are really only an application of Ohm's law and a little careful thinking to such cases.

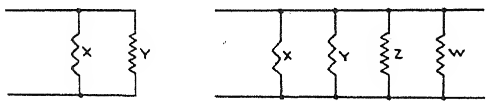


FIG. 45. Parallel resistance cases.

In the following paragraph are two useful formulas for finding the total resistance of parallel circuits. Voltage or current values are not needed to find the resistance of such circuits where all branch resistances are known. Both of these formulas can be reduced to the same form, since both have the same source. They are:

For only 2 resistors, X and Y, in parallel:

$$R_t = \frac{X \cdot Y}{X + Y}, \ X \text{ and } Y \text{ given in ohms.}$$

For more than 2 resistors (say X, Y, Z, W) in parallel:

$$R_t = \frac{1}{\frac{1}{X} + \frac{1}{Y} + \frac{1}{Z} + \frac{1}{W}}, \text{ all in ohms.}$$

These two cases are shown in Figure 45.

Examples: Case 1. Given a 10-ohm coil and a 20-ohm resistor in parallel, find their combined resistance.

$$R_t = \frac{X \cdot Y}{X + Y} = \frac{(10) \cdot (20)}{(10) + (20)} = \frac{200}{30} = 6\ 2/3 \text{ ohms, total.}$$

Case 2. Find the combined resistance value of a 6-ohm coil paralleled with a 12-ohm and a 3-ohm resistor.

$$R_t = \frac{1}{\frac{1}{X} + \frac{1}{Y} + \frac{1}{Z}} = \frac{1}{\frac{1}{6} + \frac{1}{12} + \frac{1}{3}} = \frac{1}{\frac{7}{12}} = \frac{12}{7} = 1\ 5/7 \text{ ohms.}$$

Note that, in all parallel circuits, the total resistance must be **less than the resistance of any one branch.** These two formulas are easily remembered, and are easy to use on problems involving parallel circuits.

50. Resistance Networks. Sometimes circuit parts are connected both in parallel and in series. Such a circuit, as shown in Figure 46, is possible in radio sets or transmission systems. But in these networks, or compound circuits as they are also known, the simple rules of series and parallel circuits still hold good, when properly applied.

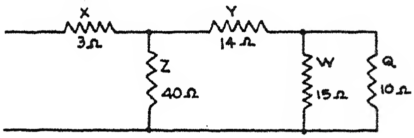


FIG. 46. A typical network or compound circuit.

In all cases where the total resistance is desired, merely begin at the "closed" end of the diagram (W and Q) and work toward the other end in simple parallel or series units of the circuit. The case shown in Figure 46 will be solved thus, as an example:

1. Take W and Q as a simple parallel circuit,

$$= \frac{WQ}{W + Q} = \frac{(15) \cdot (10)}{(15) + (10)} = \frac{150}{25} = 6 \text{ ohms.}$$

2. Add in Y as a straight series part,
$= 6 + 14 = 20$ ohms.

3. Combine this 20 ohms with Z, as parallel branches,

$$= \frac{(20)\ (40)}{(20) + (40)} = \frac{80\not{0}}{6\not{0}} = 13.33 \text{ ohms.}$$

4. Add in X as a series part,

$$= 13.33 + 3 = 16.33 \text{ ohms. Total.}$$

It is not necessary to remember this method of solving a resistance network. It was given here merely to show how the simple parallel and series rules may be used to solve the more complex circuits.

51. Construction of Rheostats. Rheostats have many purposes, both industrial and household, such as controlling the motor speed on an electric sewing machine, adjusting the generator field current in a power house, dimming the stage lights and house lights in a modern theater, and many other common practical uses.

The type of rheostat depends largely on its use. Those for heavy-current duty, such as controlling stage lights, are made large and well ventilated so the heat generated in the resistance of the rheostat will cause no damage. The radio type of rheostat is usually small, compact, and made of a circular resistance section set in a bakelite molded base, with a rubber knob on the adjusting shaft. But in all cases, the principle of the rheostat is fundamentally the same.

Most rheostats are merely adjustable resistances, made so that a wide range of resistance values is possible by adjusting a contact blade of some sort. A water rheostat, however, is used to a great extent in amateur laboratories. This rheostat can be readily made of simple home materials.

Experiment 23. Making a water rheostat. Materials needed: a large glass jar, such as a pint-size fruit jar; some flat, bright tin or sheet copper; miscellaneous — wood, binding posts, etc.

Make sheet-metal pieces, as shown in Figure 47, to serve as the two electrodes of the rheostat. Cut the strips of metal about 1½ in. wide by 6 in. long.

Make three wooden pieces, as shown in Figure 47, to support and separate the two metal strips. The assembly may be held

together with string wound around the wooden blocks. Strip X must be securely fastened, but strip Y must be adjustable up and down with slight pressure.

Pour the jar about 2/3 full of water. Hang the electrode assembly down into the water. Connect as shown in Figure 47, to use as a rheostat in a lamp circuit.

Adjust the movable electrode up or down in the water to change the resistance. How does the rheostat operate? What adjustment makes less resistance? Add a pinch of table salt to the water. What effect does this have on the rheostat action? Why does the water get hot?

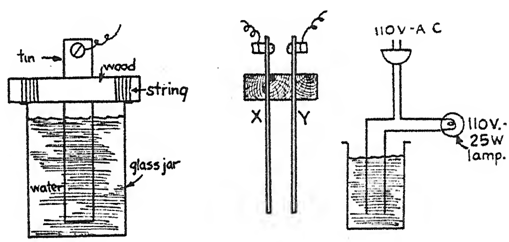


FIG. 47. Details of water rheostat.

52. Why Long Power Lines Are Impractical. Long power lines have a reasonably high resistance in proportion to the length of the line. This resistance will automatically cause a severe voltage drop in the line when a useful amount of current flows in it.

For example, consider a power line long enough to have a resistance of 100 ohms. This line, when carrying a current of 55 amperes, would have a loss or voltage drop of (55)(100) or 5500 volts. Such a loss would represent about half the power on an 11,000-volt line, or, in other words, the line would be only 50 per cent efficient.

All of this simply means that very long transmission lines or power lines are so wasteful as to be impractical. Power from Niagara Falls could not be efficiently delivered to such distant places from Niagara as Florida, Texas, or California. Most of the so-called superpower schemes leave out this idea of IR drop in the lines.

Chapter IX discusses one possible solution of this problem of transmission of power over medium distances, by using a.c. equipment such as step-up and step-down transformers. But d.c. transmission is always definitely limited to relatively short distances, with the equipment known at present.

53. Why Ocean Cables Are Poor. Transoceanic cables also have a very high resistance because of their size. Since a ½-in. diameter copper wire would have about 1500 ohms for the length needed from New York to London or Paris, such a cable, even at only 50 per cent efficiency, would require about 3000-volts pressure to deliver 1 ampere. This heavy voltage would seriously injure the cable insulation.

Another reason for these cables being at best poor devices for communication is because of their certain peculiar characteristic of inductance. This characteristic causes signals to run together into a jumbled output signal at the receiving end. To avoid this strange effect many of these cables have been made of special construction materials, but even these lines are not totally free of this annoying effect, for which there is no entire cure. Telephone messages are quite impossible over these cables. Only telegraphic signals can be sent over them, and these must be slow signals.

The radio telegraph and the radio telephone have recently come into common use, on the shorter wave lengths, for all the transoceanic messages and programs. While not perfect, the radio does offer simpler and more stable transoceanic communication.

54. Why Power by Radio Seems Impossible. Here again the problem finally reduces to one of Ohm's law. The *IR* drop over even a few yards of air is extremely great, cutting down the received power to a minute per cent of that actually transmitted. Such very high inefficiency can never be tolerated in a world that pays heavy costs for all power, used or wasted. While many schemes are evolved every few years for a power-by-radio system, yet when actually tried out, each of them fails miserably to do the job well enough for practical use.

55. Why Old Dry Cells Are Weak. A dry cell slowly loses its power, even when not used as a source of energy. There are two main reasons why dry cells lose power:

1. The electrolyte or acid inside the battery slowly acts on the zinc can of the cell, although no current is being used in any

circuit connected to the cell. This action slowly but surely eats away the zinc, and thus lessens the life of the cell. On the average, a No. 6 (large) dry cell will greatly weaken in 9 months standing idly on a shelf.

2. Another reason why a dry cell, when used for a few minutes at a heavy current drain, seems to die down, is called "polarization." (This has nothing to do with magnetic poles.) Hydrogen is released as a gas in a battery when current is being drawn from it. This is part of the normal chemical action in a battery, and is quite similar to electrolysis in water, when hydrogen is released as a gas.

This hydrogen gathers around the + or carbon pole of a battery as a thin blanket of bubbles. These tiny hydrogen gas bubbles have a very high resistance like air. Of course this slowly increasing resistance in the current circuits slowly shuts off the current delivered. Allowed to stand idle for a few minutes or an hour, this hydrogen is absorbed by some chemicals in the dry cell, and the current again may be heavy. Thus, a flashlight, using small dry cells for a current source, must be allowed to "rest" or recuperate every few minutes for the most satisfactory service. Dry cells are best used on circuits needing only intermittent current supply. The more continuous the service demand on a dry-cell power supply, the larger must be the size of the dry cell, to keep down this effect of polarization around the carbon poles.

56. Making Good Connection. From this chapter on resistance, it can be readily seen that joints in all electrical circuits must be carefully made, for at least two reasons. First, the danger of a poorly made joint in such services as house wiring is fire, caused by heat from the poor or bad joint. Second, all joints add to the resistance of the circuit as a whole, and thus cut down the possible current delivered through the circuit by the supply-line voltage.

Several good points in making a satisfactory joint or connection in any circuit are listed here, as of general interest:

1. Clean both wires to a bright metal surface. Why?
2. Twist tightly together, with many turns in close contact.
3. Solder well, so that all surfaces of the two wires are covered evenly. Why?

Figure 48 shows the great difference between two bare wires merely twisted tightly together and the same wires not only twisted but also soldered. The soldering greatly increases the area of contact, and thus decreases the resistance of the whole joint.

For these reasons, care should be exercised in making good joints in all electrical circuits. Good workmanship in the making of splices and joints results not only in safer circuits but also in savings in power.

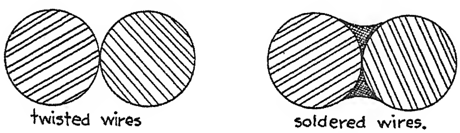


FIG. 48. Soldering increases area of contact of a joint.

SUMMARY

Resistors are merely poor conductors.
Methods of measuring resistance:

1. Ammeter-voltmeter method — $R = E/I$.
2. Ohmmeter, an instrument calibrated in ohms.

Insulators are merely very high resistances.
How wire size affects resistance:

1. Diameter or cross-section area of wire:
   Smaller wire, greater resistance;
   Larger wire, less resistance.
2. Length of the wire:
   Shorter wire, less resistance;
   Longer wire, greater resistance.

Materials all have different resistance values. Copper is the most economical conductor for practical purposes.

All conductors have resistance, and develop a certain amount of heat when carrying a current.

Series resistances: R_t = sum of all the R's.

Parallel resistances: R_t is less than any branch resistance.

Two branches (X and Y): $R_t = \dfrac{XY}{X + Y}$ ohms

More than 2 branches: $R_t = \dfrac{1}{\dfrac{1}{X} + \dfrac{1}{Y} + \dfrac{1}{Z}} + \ldots$ ohms,

where X, Y, Z, etc., are all given in ohms.

PROBLEMS

Prob. 1. Compute the resistance of a 4-mile country telephone-line wire, No. 18 B. & S. gauge copper.

Prob. 2. Trolley wire usually has a resistance of .05 ohms per 1,000 feet. Find the resistance of a 6-mile line of this wire.

Prob. 3. What voltage drop will occur in Problem 2 line at 300 amperes load? Would the line be efficient at 600 volts?

Prob. 4. If half the resistance of a standard electric iron shorts out, how much current will then flow in the iron on 110 volts?

Prob. 5. A coil is wound with about 500 ft. of No. 40 copper wire. What will the coil's resistance be?

Prob. 6. What resistance should a precision voltmeter of 250-volt range have?

Prob. 7. How much current will the meter in Problem 6 draw from a 200-volt line to operate the meter element?

Prob. 8. Estimate the voltage drop through a precision ammeter which reads 50 amperes in the line.

Prob. 9. The ammeter in the line to a heater reads 50 amperes. A voltmeter reads 325 volts around the heater. Diagram the circuit. Compute the resistance of the heater.

Prob. 10. How many times better is No. 14 gauge copper than No. 18 gauge copper wire as a conductor? (Compare the resistance of each.)

Prob. 11. In an alloy made of copper and aluminum, in equal parts, how would its resistance compare to the resistance of pure copper?

Prob. 12. If wire joints are so made that the copper wires are held apart by solder, how will such joints compare to those where copper presses hard against copper?

Prob. 13. Which wire will have the least resistance: No. 10 iron wire, or No. 18 copper wire? Refer to Tables XII and XIII for data. Which will have the lowest voltage drop at the same current?

Prob. 14. What advantage is the very high resistance of lead in a fuse?

Prob. 15. Compute the resistance of 1 ft. of No. 24 copper wire. Find also the resistance of a similar piece of steel wire.

Prob. 16. Compute the resistance of 10 ft. of No. 18 iron wire.

Prob. 17. Two 8,000-ft. lines of No. 18 copper wire are operated in parallel on a telephone circuit, in an emergency. What is their combined resistance?

Prob. 18. Calculate the number of feet of No. 40 iron wire to be wound on a porcelain tube to make a 100-ohm resistor.

Prob. 19. How many times greater is the resistance of steel than that of aluminum for a wire of the same size?

Prob. 20. To have equal resistance for the same size wire, which will weigh the most per 1000 ft.: copper or aluminum? How much will the aluminum wire of equal resistance weigh? About what fraction of the copper-wire weight is this value?

Prob. 21. Calculate from the copper-wire-table data the resistance of 350 ft. of No. 6 copper. What maximum allowable current should this wire carry?

Prob. 22. Find the voltage drop of the line in Problem 21.

Prob. 23. Find the resistance of 200 ft. of No. 10 copper wire in series with 600 ft. of No. 12 copper wire. What is the allowable current in such a line, according to Table XIII?

Prob. 24. Estimate the line resistance of a country telephone line that uses 2 miles (5,280 ft. to the mile) of No. 18 iron wire.

Prob. 25. If the current in the line of Problem 24 is .1 ampere, what voltage drop will occur?

Prob. 26. A resistor must be made to have .150 ohms. How many feet of No. 20 copper wire will be needed? Will the finished coil carry safely 3 amperes?

Prob. 27. What length of No. 30 copper wire would be needed to make the resistance coil of Problem 26 (.150 ohms)? Would this new coil safely carry the 3 amperes? Why?

Prob. 28. A brass rod measures .204 in. in diameter by 10 ft. long. What resistance does it have, approximately?

Prob. 29. In a stranded wire cable, all strands are in parallel. Find the resistance of 100 ft. of copper cable, made of 16 strands of No. 24 wire.

Prob. 30. Find the resistance of a 500-ft. line of copper cable, made of 7 strands of No. 12 wire.

Prob. 31. Calculate the resistance of 16 ft. of No. 22 gauge nichrome wire to be used in an electric furnace. What current will the furnace draw on a 110-volt line?

Prob. 32. Find the total resistance of the four field windings of a motor when connected in series. Each winding consists of 60 ft. of No. 30 gauge copper wire. How much current would these coils draw on a 110-volt line?

Prob. 33. Calculate the combined resistance of a 50-ohm coil in parallel with a 100-ohm resistor. How much current would each branch draw on a 400-volt line? (Check this problem by using Ohm's law on the total voltage and total current, to find again the total resistance.)

Prob. 34. Calculate the combined resistance of three 60-watt Mazda lamps in parallel. (Check as in Problem 33, using 120 volts.)

Prob. 35. How much current would three 60-watt Mazda lamps in **series** draw on a 120-volt line? Would they light?

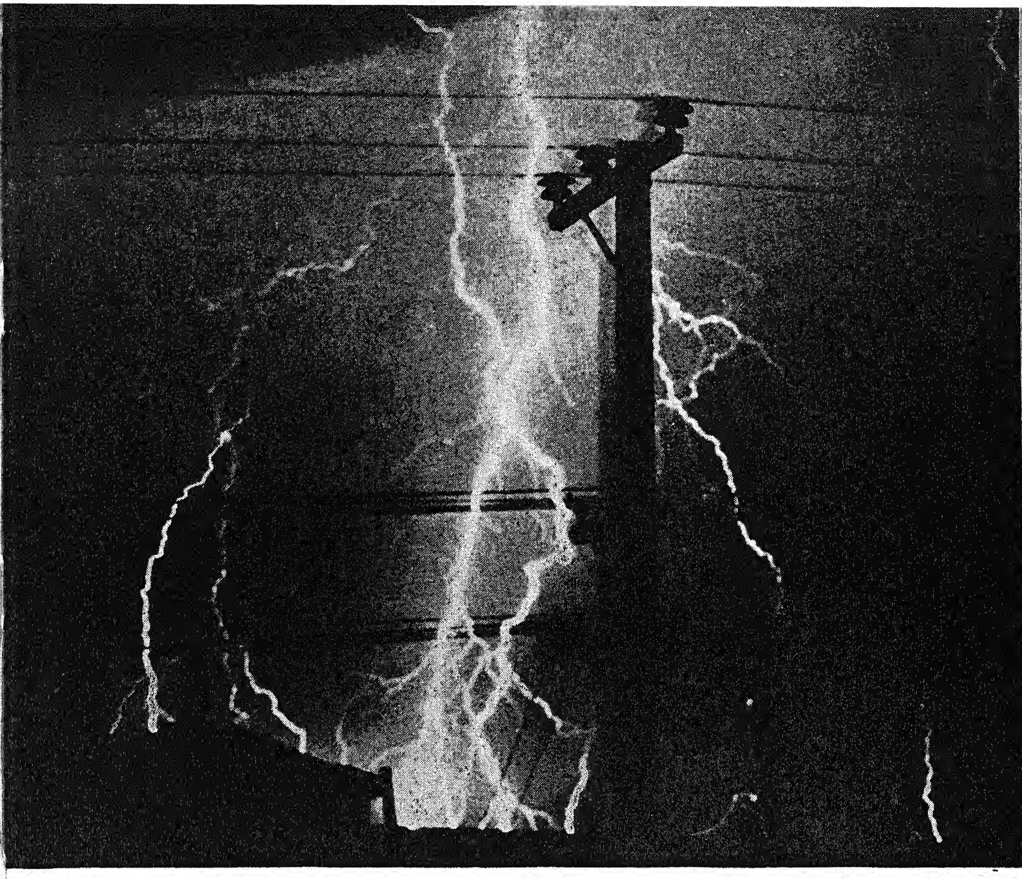
Prob. 36. Will a 60-watt Mazda lamp light, in series with a 550-watt electric iron, on 120 volts? What voltage would be needed to deliver .5 ampere through the series combination?

Prob. 37. A rheostat is found to pass 6 amperes, with a drop of 39 volts. What is the resistance of the rheostat? At 12 amperes, what voltage drop would occur in the rheostat?

Prob. 38. Suppose a new dry cell, on short circuit, gives 30 amperes at 1.2 volts pressure, and only .05 amperes at 1.0 volt after severe use. How much internal resistance did the cell have at first and after use? What caused the great increase?

Prob. 39. If twisted joints in telegraph wires have a resistance of 7 times the resistance of the wire per foot, find the resistance of five 1000-ft. sections of No. 16 copper wire in series, counting joint resistances.

Prob. 40. A 100-ft. extension line from a house to a garage must carry 30 amperes, with a drop of only 5 volts. What size wire will be suitable for the line? (Wire length is total of 100 ft., counting all connections.) Find the resistance of the line per 1000 ft. of wire.



— General Elec. Co.

NATURE DWARFS MAN'S WORKS

The tremendous voltage behind a stroke of lightning defies man's relatively puny attempts at insulation. Nothing is safe from the high voltage of such a flaming streak of electrons as this. Only the camera lens dares look unflinchingly at such a magnificent display of the power of the electron when loosed from mile-high rumbling clouds to the trembling earth below.

Damage from such direct strokes as this one is enormous. Lines burn down, insulators shatter, and power equipment for many miles is affected seriously. Operators are endangered, but nevertheless, these men stay on duty.

Chapter IV

VOLTAGE: PUSHING ELECTRONS

WITHOUT voltage, electrons would never move along a circuit path to do their assigned tasks. To keep electrons moving, voltage must be constantly applied to the circuit. The voltage needed in any case depends on both the current to be delivered and the resistance of the path. By Ohm's law, the voltage on a circuit is known to be equal to the current in the circuit times the resistance of the circuit: $E = IR$.

58. Common Voltage Values. Some of the everyday values of voltage in the home and out in the world of industry and commerce are listed in Table XIV. These values are by no means absolute; the actual measured voltage in similar cases to the ones listed may vary somewhat from the values given. But, in general, this list is representative of average cases. The d.c. and a.c., of course, mean direct current and alternating current.

TABLE XIV. COMMON VOLTAGE VALUES

	Volts
Dry cell	1.4 to 1.5 d.c.
Lead storage battery, per cell	2.0 d.c.
Lead storage battery — 3 such cells in series	6.0 d.c.
House light and power lines	110 a.c.
Street-railway trolley line	550 to 750 d.c.
Ford spark coil	about 1,500 a.c.
Power distribution lines	1,100 or 4,000 a.c.
Power transmission lines	11,000 up to 220,000 a.c.
Street lighting circuits	up to 30,000 a.c.

59. Why Lightning Cannot Be Harnessed. Ever since Benjamin Franklin's experiment with his kite on a stormy night,

lightning has been known to have a very high voltage. The extreme damage that a direct stroke of lightning can do is well known. Trees are split by it as if by some mighty ax wielded by some great giant. Little wonder the ancient barbarians feared lightning, and offered up sacrifices to the god Thor. The miracle of Franklin's experiment is that he was not electrocuted when his kite wire delivered the charge of the cloud to the earth. Less than a year later, a noted Russian scientist was electrocuted when performing an experiment similar to Franklin's.

The voltage of lightning is enormous. Roughly, it requires about 25,000 volts per inch of gap for a spark to jump between points. Imagine the voltage of a stroke of lightning between a cloud 1,500 feet high and the earth!

Quite obviously, such extremely high voltage defies all efforts to insulate or to control it in any way. Therefore, it has no practical value as a reliable source of power, and cannot be harnessed to any reasonable task.

Incidentally, lightning always strikes the highest and nearest point, in a discharge, such as a high spire or tower, or a lone tree out in the open country. Lower objects near the high one are relatively safe from direct strokes. It would, however, be very unwise to take shelter under a lone tall tree out in the country during a storm. Any discharge to the tree would be likely to kill man or animal under it.

Lightning rods on buildings must be installed without any sharp angles or short bends in the ground rod, to be of surest protection. Such high voltages as lightning often drive the electrons in rather straight lines, disdaining bends altogether.

However much we may want to harness the great energy of lightning, its voltage will always be an insurmountable obstacle, preventing success along this line. The best that can be done is to gain a fair degree of protection from lightning.

60. Insulation on High-Tension Lines. Transmission lines are usually strung on high poles or steel towers. Bare wire is used for the conductors, supported by special porcelain insulators. These insulators must be perfect, with no cracks or any leakage paths in them for current. In addition to insulation, these porcelain insulators must be very strong to withstand the weight and pull of the wires.

Line insulators also have to endure all kinds of weather — hot,

cold, rain, dust, ice, and snow — without leaking. This means that all outdoor insulators must not only be made of a fine grade of porcelain for insulating quality, but must also be very sturdy and well glazed or varnished. Glazing prevents water soaking into the porous insulator, which would reduce its insulating value greatly.

High-tension lines usually are insulated by strings of insulators in each wire, as shown in Figure 51. Each insulator does its share of the job of insulating the line from the tower.

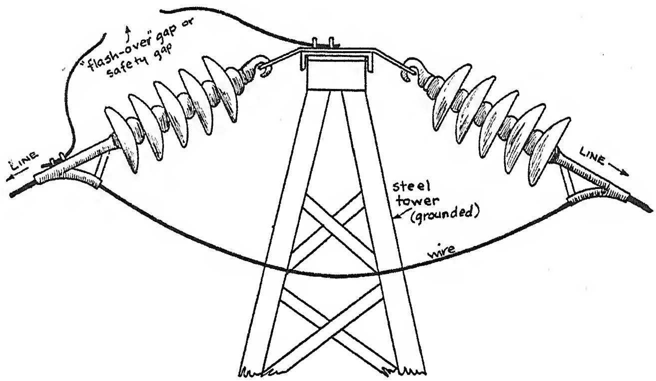


FIG. 51. High-tension insulator strings.

Flashover gaps are sometimes made of heavy wire and are put in place by the construction crew. Such gaps act as lightning arrestors, and prevent the costly insulators from being cracked by extremely high voltage, such as lightning or a line surge.

Suppose that one insulator can safely stand only 4,500 volts without any flashover. Then, to properly insulate a 22,000-volt line, each string of insulators would need at least 5 such units in series, as shown in Figure 51. Sometimes when such insulator strings are installed, several more than the minimum number of units is used in the strings for safety.

61. Batteries As a Voltage Supply. The common source of electrical energy for portable uses, such as in flashlights, is the dry cell. Wet cells such as the lead storage battery are used in such places as automobiles, to supply the various low-tension circuits with current.

Batteries are made in many types and sizes, depending on the use to which they are to be put. Ordinary dry cells, using a carbon rod and zinc can, make up the common type of battery used for many purposes. The size and number of such cells needed for any particular task depend upon the voltage needed and the current demand.

The average new dry cell of any size has between 1.4 and 1.5 volts pressure, as given in Table XIV. Thus, three such cells in series would have a voltage of about 4.5 volts.

Large batteries can give more current than small batteries, because large batteries have a larger supply of "fuel" available at any instant. For example, a large No. 6 dry cell can deliver up to 30 amperes on short circuit. A tiny, slender dry cell, such as is used in small, pen-type flashlights, can deliver only about .8 ampere on short circuit. The amount of zinc exposed, in each battery can, accounts for this difference in current delivering ability. Where heavy current is needed, large cells are used. The average flashlight lamp requires very small current, about .2 ampere, so small cells may be used. Where 2.8-volt lamps are used in small flashlights, then two 1.5-volt cells are used in series, supplying about 3 volts to the lamp. The .2-volt excess will be absorbed in the various parts of the complete circuit, as a line *IR* drop, when the current actually flows.

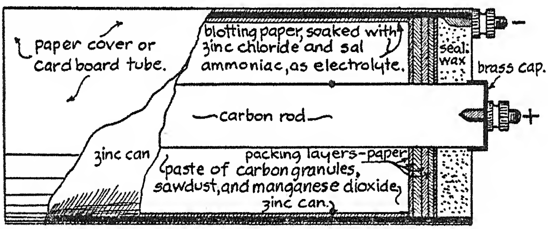


FIG. 52. Cross section of a dry cell.

A cross-sectional view of a dry cell is shown in Figure 52, with all the details labeled. A dry cell is only "dry" because the sawdust inside it keeps the electrolyte all soaked up, so it cannot pour or leak out. When in any dry cell the zinc is all used up, the cell is of no more use. It cannot be recharged as is possible with storage batteries.

62. Construction of a Simple Cell. A very simple "wet" cell may be made as an experiment, to show how batteries generate energy for small services. A simple homemade wet cell will light a small 1.2-volt lamp nicely.

Experiment 24. Making a simple cell. Materials needed: a water glass or jelly glass; a strip of zinc about 1 in. by 5 in.; a similar strip of copper; ½ ounce of sulphuric acid (poison).

Bend the zinc and copper strips so they will fit down over the glass sides as shown in Figure 53. The two strips may be held in place firmly with string wound around the glass and tied.

Nearly fill the glass with water, as shown. Add about 2 teaspoonfuls of sulphuric acid to the water. Pour it directly into the water. **Do not use a metal spoon** to measure the acid; guess at the amount, as slightly more or less will not make much difference. The acid is poisonous — **keep it away from hands, face, and clothes. Never pour water into acid; always pour acid into water.**

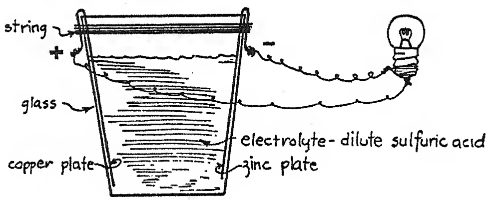


FIG. 53. Simple cell details.

The cell may now be connected to a small 1.2-volt flashlight lamp, which should light nicely. Note that gas bubbles form all over the + (copper) pole of the cell. These are bubbles of hydrogen, and slowly shut off the current when the cell is used continually for a few minutes (see Art. 55).

Note that in a commercial "dry" cell (made "dry" merely by adding enough sawdust to soak up the liquid electrolyte) the hydrogen "blanket" of bubbles forms around the carbon pole. Carbon and copper act quite similarly in a cell of the types here discussed. But in commercial cells, a chemical (manganese

dioxide) is added to absorb the hydrogen as quickly as it is released at the carbon (+) pole.

If, in the experimental battery shown in Figure 53, the copper plate is covered with a cloth bag containing a little manganese dioxide, the hydrogen will be quickly absorbed. This measure will reduce polarization to a small enough value so that the simple homemade battery can be used as a constant source of energy.

Larger plates will produce more current. Connecting such cells in series will give greater voltage. Do not short circuit such batteries, as this simply wastes the energy. When the cell is not to be used for a long time, empty the acid into a covered or corked bottle, for safekeeping, where no harm will be done. Even the fumes from sulphuric acid will slowly injure clothing or varnished surfaces near by.

63. How Battery Chemicals Produce Electricity. The chemical actions that go on in a battery when it is delivering current to a load do not actually produce that current. These chemical reactions do, however, liberate into a current some of the electrons always present in such materials as zinc, copper, and sulphuric acid. Several facts you probably already know will help to explain how this current develops in the battery you made and used in Experiment 24.

You know that zinc dissolves slowly in sulphuric acid. Zinc, like all metals, has innumerable electrons in it. And when this zinc (Zn) dissolves in the sulphuric acid (H_2SO_4), each particle leaves its electrons behind, on the remaining zinc plate. These liberated or "free" electrons can now move along any metal conductor easily, because they are no longer tightly anchored to particular zinc particles. These excess free electrons, always — charges, make the zinc plate of the battery strongly negative in polarity, instead of neutral as before the acid began to dissolve its particles.

The dissolved zinc particles are called *ions*. Ions are simply particles that are charged — or + . Sulphuric acid has two sets of ions; the H_2SO_4 liquid is really + ions of H_2(hydrogen) and — ions of SO_4(sulphate ions). Keep in mind that like charged ions will repel, unlike charged ions will attract.

The particles of zinc which are dissolved must be positively charged (+ ions), because they have lost their electrons when dissolved. These + zinc ions combine with the — sulphate

(SO_4) ions present in the acid electrolyte, to form zinc sulphate $(Zn\ SO_4)$. $Zn + H_2SO_4 = Zn\ SO_4 + H_2$.

Think again about the negative (—) charges on the zinc plate, all closely crowded together. They normally repel, as is the law of like charges. When a path presents itself, these electrons rush out along it, to finally reach the copper plate of the cell. These —charges on the copper plate attract the +charged hydrogen ions in the electrolyte. Thus, the hydrogen bubbles collect on the + pole or plate of the cell, whether it is copper or carbon as in commercial types.

Here is an astounding fact that gives some idea of electrons, their number and size. Suppose a current of 1 ampere flows for 1 second out of this battery or any other power source. Suppose these electrons are to be counted. The job would require 1,000,000 persons, working continuously, counting at the rate of 2 electrons per second, about 10,200 years to complete. Think how very tiny an electron must be, and how very fast it must move in a wire, when pressure is applied by a battery or a generator.

Just incidentally, when electrons are moving with a pressure of 1000 volts behind them, their speed is about 12,100 miles per second. Even at a pressure of 1 volt, electrons have a speed of about 383 miles per second. X-ray particles, in tubes having 100,000-volts plate potential, travel at about 121,000 miles per second. Such facts are very striking, compared to man's small accomplishments in speed devices. (See Problem 38, Chapter IV.)

64. The Storage Battery and Its Care. Storage batteries have become very common since the automobile began using them as a source of starting and lighting power. The usual type of such storage batteries is the 3-cell lead storage battery, with a wooden or rubber case holding the cells firmly in place to prevent damage to the rubber cell jars. Tar is usually poured in around the individual jars of a 3-cell battery to hold them in place.

It is not necessary to know very much about a lead storage battery to understand how to care for one in operation. The storage battery is **not** a sort of condenser where electricity is stored up. In a storage battery, as in any other battery, the electrical energy comes from the various chemical changes in the cells.

The charging process consists in forming certain chemical

substances by passing electricity through a solution, just as hydrogen and oxygen are formed in the electrolysis of water. In the discharging process, electricity is liberated by the substances which were previously formed in the charging process. What these various chemical substances are is of no great importance here. But the care of the operating cycle of such a battery is quite important, and is detailed here.

CARE OF THE STORAGE BATTERY

Care of the case:

1. Keep the wooden outside case clean and strong.
2. Never drop the battery.
3. Keep battery supports or clamps tight, to decrease jarring.

Care of the terminals:

1. Keep the lead terminals clean and covered with clean grease.
2. Make all cable connections to terminals very tight.
3. Never allow cable connections to vibrate or wiggle.

Care of the battery:

1. Keep the battery well charged — up to "1275, gravity."
2. Keep the electrolyte well over the plates.
3. Add only distilled water; never add acid.
4. Never short circuit a storage battery.

These simple rules, when carefully followed, will greatly increase the average life of a storage battery.

65. Charging a Storage Battery. The charging process is needed whenever the electrolyte in the battery cells indicates it. To test a battery for its condition of discharge, a special device called a hydrometer is used. This instrument usually is made of a long glass tube, a rubber suction bulb, and a graduated float, as shown in Figure 54.

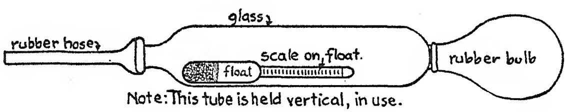


FIG. 54. Hydrometer for testing a storage battery.

The battery acid is sucked up into the large glass tube, and the position of the weighted float is noted. If this reading is less than about 1150 (or 1.15 times as heavy as water), the

battery needs charging. When fully charged, the battery acid will support the float at about 1275 (or 1.27 times as heavy as water). The useful range of a battery's operating cycle is thus between an acid gravity of 1150 up to 1275.

When the "charge" goes below 1150 (say 1140 or less), the battery must be charged by forcing current through it in an opposite direction from the battery's normal delivery. Figure 55 shows the proper connection for this. The charging line must supply d.c. power; a.c. will not charge a storage battery. The voltage of the charging line to a 6-volt storage battery should be about 10 volts, or 4 volts in excess of the reversing voltage needed to force current backwards through the cells. Two such batteries, charged at once, in a series connection, would need about 20 volts applied to them.

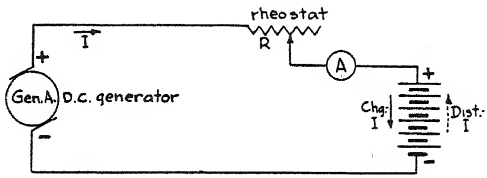


FIG. 55. Storage-battery charging connections.

For best results, the charging current should be about 15 amperes in the beginning, tapered down to about 1 ampere at the end. The rheostat R is inserted in the line to the battery to provide this variation in charging current. The supply line may come from either a d.c. generator or a special rectifier, to change a.c. to d.c. for the purpose of charging batteries.

66. Generators as Voltage Supply. If we had to depend on batteries alone for all our voltage supply, then there would be few street and house lights, no modern theaters, no street cars, and no radios such as now are in common use. The high cost of the zinc needed as a fuel in batteries would not allow such uses of current.

The vast electrical power in such common use comes largely from great generators, which convert mechanical energy into the desired electrical form of energy.

Two men, Michael Faraday and William Henry, about 1831

discovered that it is possible to transform mechanical energy into electrical energy, by a relatively simple process. This method of producing electrical energy by means of wires being whirled through strong magnetic fields is the basic principle of the commercial generator, which has made possible this modern age of cheap electricity. In fact, the generator has revolutionized modern industry and the modern home, by furnishing a reliable source of power to perform a thousand different tasks.

Generators may be driven by many kinds of motive power, including steam engines, steam turbines, water wheels, water turbines, gasoline engines, gas engines, and oil-burning Diesel engines. These power plants convert the coal pile or the oil in a fuel tank into a mighty stream of rushing electrons, ready to serve man in his work or amusement, at the touch of a button or the throw of a switch.

Generators are made in many sizes, depending on the power to be developed. Automobile generators are small — about 6 in. in diameter and 9 in. long. On the other hand, the huge machines used to generate the power for a large city distribution system are sometimes 20 ft. high and long, and weigh many tons. Their shafts are sometimes 24 in. in diameter.

The principle of all generators, large or small, is exactly the same in all cases. It is simple, and is as follows: Whenever a wire is moved through lines of flux, or lines of flux are moved (moving magnet) so they "cut" a wire, a current will be generated in the wire. Some further details, explanation, and experiments will make this principle clear.

67. The Magneto as a Simple Generator. The simplest type of generator in common use is called a **magneto,** because it uses permanent magnets to supply the necessary magnetic flux. A magneto usually has several U-shaped bar magnets clamped firmly together on some kind of frame as shown in Figure 56. Inside these magnets, revolving between their *N–S* poles, is a small, soft iron armature, wound with many turns of wire. Usually, gears are used to make this armature turn faster than the hand crank on the machine.

The strength of the magnets, the number of turns of wire on the armature, and the speed of the armature (rev. per min.) determine the voltage generated by the magneto. Some magnetos

("mags") are made to generate as much as 125 volts for operating special telephone circuits. When applied to small gas engines, such as on a motorcycle, special "high-tension" magnetos are made, to deliver energy directly into the ignition distributor and on to the spark plugs. Low-voltage magnetos (6 v.–15 v.) are made for general use. A magneto is usually a hand-driven machine, but may be motor-driven.

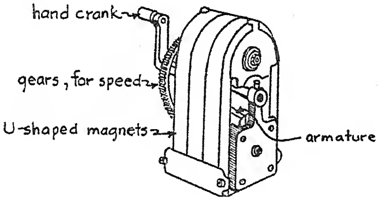


FIG. 56. Magnetos have permanent magnet fields.

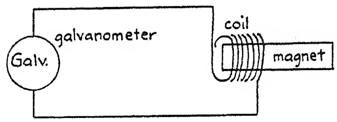


FIG. 57. Generating current in a coil.

68. Principle of the Generator. Faraday discovered by accident that when a copper disk was whirled between the poles of a magnet, so that the flux lines cut the conductor as it moved, the copper disk had a voltage generated in it. The same experiment with a coil of wire, rapidly rotated in a strong magnetic field, will produce the same effect in a more noticeable way.

Experiment 25. Generating current in a coil. Materials needed: a permanent magnet or an electromagnet and a dry cell to energize its coil; a coil of wire (about 25 ft. of No. 26 insulated copper will do); the galvanometer and magnetic compass made in Experiments 9 and 12; some insulated wire for long connections.

The galvanometer will serve very nicely as an indicator of the small current that is generated when a magnet is moved so the flux lines "cut" a coil of wire. The experiment setup is simple enough to make, so that only a diagram of it is given in Figure 57.

Make a test coil of about 30 turns of insulated wire. This coil must be large enough in diameter to pass easily over the magnet to be used, without scraping or touching. Tie the turns of the coil in place with thread or string wrapped around them. Leave leads, twisted together, about 36 in. long or more.

Connect the test-coil leads to the galvanometer-coil leads or terminals. Set the galvanometer coil so its axis is due East-West. The compass needle will thus normally point *N–S* parallel with the galvanometer-coil turns.

Place the magnetic compass on the shelf provided for it in the center of the galvanometer coil. A special compass-needle support bearing may be permanently attached to the galvanometer-coil shelf, if desired, as a permanent improvement.

Block the galvanometer firmly against vibration with a book or two, so it will not wiggle or move when the test coil is operated.

Now slip the test coil over the magnet. (If an electromagnet is used, keep it energized constantly from a dry cell near by.) Does the galvanometer needle move when the coil and magnet are moved on each other? Any needle movement indicates that the galvanometer coil is carrying current. Where is this current generated? Is the mechanical energy of the moving magnet transformed into the electrical energy noted?

Try moving the coil only. Then try moving the magnet only. Does it matter which one is moved to generate the current?

Try moving the magnet in and out of the coil. What does the compass needle do? Does this alternating motion produce an alternating current? (Yes.)

Try reversing the magnet. Do opposite ends of the magnet affect the generated current direction any? How? Does an in motion produce the same results as an **out** motion of the magnet inside the test coil?

Try out the effect of a slow, medium, and fast motion of the magnet on the current generated. Which produces the greatest current, judging by the amount of swing of the galvanometer needle?

Make careful record of the results of these details of this experiment. Use little sketches of the detail tested, and show by arrows the motion of the coil or magnet, all properly labeled with +, —, *N*, and *S* signs. (Use the R.H.R. for a coil to determine which are the + and the — leads of the coils.)

This little experiment explains exactly how and why a simple magneto or generator operates, when driven by some power outside itself, converting this mechanical energy into electrical energy.

A very sensitive ammeter (a milliammeter, reading in thousandths of an ampere) may be used in this experiment in place of the galvanometer suggested. Such a meter may be read directly in the amount of current generated in any particular case outlined in this experiment.

69. Right-Hand Rule for Generators. There is a special rule for the generator, similar to the ones for a straight wire and for a coil of wire. This generator rule relates the direction of flow of the flux cut, the direction of motion of the wire in the flux, and the direction of the generated voltage and current in the wire being moved. Knowing this rule makes it clear which way to wind a generator magnetic-field pole, or how to turn the generator armature to produce the desired current direction.

Experimenting with a strong field, a moving wire, and a very sensitive instrument, such as a millivoltmeter or galvanometer, to indicate the amount and direction of the generated current, will make the rule quite clear. First of all, a special electromagnet should be made, as in Experiment 26, to produce the very dense magnetic field necessary in some later experiments. A double-magnet scheme produces the best field for such experiments as are to follow. By slight changes, such a double-magnet setup can be used later for many a.c. experiments.

Experiment 26. Making a special electromagnet. Materials needed (similar to Experiment 5): two soft-iron, flathead bolts, about 1½ in. long, ¼-in. shanks, with nuts; cardboard and heavy paper for magnet construction; about 75 ft. of No. 26 insulated copper wire, for the magnet windings; some heavy tin (sheet iron).

Refer to Experiment 5 for the details of making the two simple electromagnets needed here. Make two, exactly alike, with about 100 turns of No. 26 insulated wire on each. Be careful to insulate the bolts before wrapping on the wire turns. Cover the outside of the magnets with paper, if desired, for a neat job.

Leave leads about 12 in. long on each magnet. Tie a knot or color the leads on each magnet that wind in the same direction around the coil. This will help a great deal in connecting the magnets to get certain polarities at their ends. Coil the magnet leads into neat "pigtails," around a pencil, as in Experiment 5.

Make a heavy sheet-iron (tin-can metal is sheet iron, tin plated) frame to support the magnets, and to carry the return flux between the outside poles of the magnets. This frame, details of which are shown in Figure 58, must be very rigid. The frame or yoke must be so made that it will hold the magnet pole faces about ¼ in. apart, as shown.

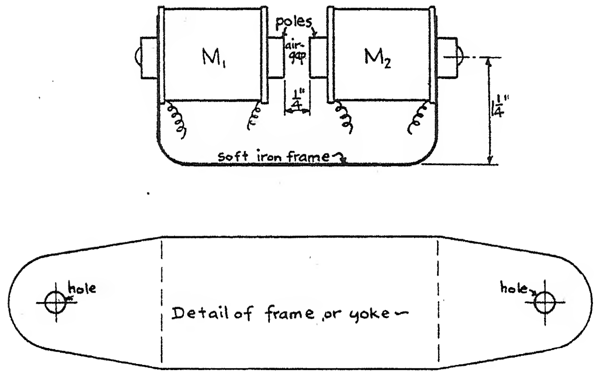


FIG. 58. Special double-coil electromagnet.

The yoke, or frame, must be absolutely rigid, to prevent the magnet pole faces from moving apart or together, when strongly energized from a battery. If one piece of tin is not stiff enough to do this, then use two layers of tin together, to get the desired strength. Bending ridges in the tin also will add strength to the yoke.

Remove the end nuts on the magnets, and reassemble them on the yoke just made, as shown in Figure 58. The completed unit may be mounted on a wooden base, if desired, but this is not necessary. If the tin has any rough or sharp edges that might cut the fingers, they can be smoothed or rounded with a file or emery cloth. The assembly is now ready for use in Experiment 27.

The coils of this double magnet may be connected in several different ways. They may be operated in parallel or in series, on a single dry cell. For most economical operation on one No. 6 dry cell, a series connection is best.

The magnets may be connected to have two N poles facing,

or two S poles facing, or a N–S combination of poles at the air gap. When connected to have like poles facing on the gap, the pole fluxes will repel. But when connected so that unlike poles face, either N–S or S–N, the flux in the air gap will be straight across between the poles, and very dense or heavy. Any small iron objects will be very strongly attracted to the gap. Try this out.

Experiment 27. The principle of the generator. Materials needed: complete galvanometer, with supersensitive magnetic needle; the special double-coil electromagnet made in Experiment 26; a No. 6 dry cell to energize the magnets; some insulated copper wire for connections.

First connect the two magnets on the yoke so their coils are in series, and produce unlike poles at the gap. Be sure to check which is N and which is S. If any doubt exists, use the compass needle to check the poles, as in Experiment 7. This must be known to be able to tell which way the flux is moving between the pole faces (always from the N to the S pole). See Figure 59 for these details.

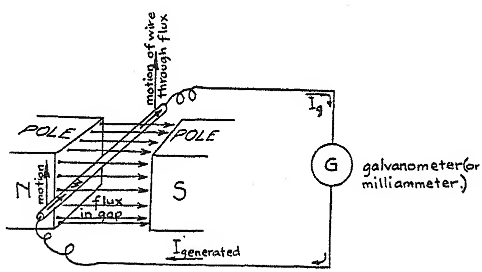


FIG. 59. Generating an e.m.f. in a wire.

Arrange the coil connections to the dry-cell battery so that one lead may be disconnected easily to act as a switch in the circuit. This will help to conserve the energy of the battery.

Connect the galvanometer with long leads (48 in.) to a section of stiff wire, as shown between the pole faces in Figure 59. The same wire as the leads may be used, if heavy enough to stay in shape as it is moved up or down in the magnetic flux.

Set the galvanometer so the compass needle is normally parallel

to the galvanometer-coil winding, as was done in Experiment 25. Brace the galvanometer so it does not wiggle.

Close the magnet-coil circuit to the battery. Now there is a constant flux across the gap between the pole faces, from *N* to *S*.

Rapidly move the wire *W* up through this flux. The galvanometer needle will deflect, indicating a generated current. Move the wire *W* down through the gap, cutting the lines in the opposite direction as before. This should reverse the direction of the generated current. Does the galvanometer needle reverse?

Open the battery circuit. Try the wire motion now. Does it generate any current? Why? What conditions cause a generation of current?

Hold the wire *W* still in the gap. Does it generate an e.m.f. now? Why?

Here you have the basic principle of all generators. A generator is merely a neat mechanical device which whirls many wires through a heavy flux field, thus generating current in the wires. All generators work on this same principle. Of course, some arrangement such as brushes must be made, to have a sliding contact so the moving coils of the armature can be kept connected to the line all the time. This sliding-contact arrangement is known as a "commutator and brushes," common on motors and generators.

Experiment 28. Generating greater voltage. Materials needed: same as in Experiment 27.

Connect and operate the double-coil magnet as in Experiment 27, to produce a very dense flux, when it is needed, in the pole gap.

Replace the single wire *W* with a group of conductors in series. Do this by making a 10- or 15-turn coil of No. 26 wire on a form about 3-in. square. Hold the turns firmly together by winding them with thread or string. Leave long leads on the coil, to connect to the galvanometer as in Experiment 27.

Use the turns on one side of this square coil as the wire *W* was used in the previous experiment. Cut the pole flux rapidly, downward. Note the galvanometer-needle movement or deflection. Bring the series turns upward through the magnetic flux. This reverse of the motion should reverse the generated current. The reversed current also will throw the galvanometer needle the

opposite way. Check this carefully by actual tests. Keep a record of the results noticed.

Apply the right-hand rule for a coil to the galvanometer, to determine which deflection of the needle indicates + and — leads. Now trace out the test-coil leads, to check which way the current flows in the coil turns when they are moved up or down in the pole flux.

Do more turns in series, all cutting the same flux, generate a greater voltage than just the one conductor, as in Experiment 27? Why? Try out a coil of about 50 turns or more of very small wire, in this respect. It should produce a much greater needle deflection.

If the compass needle is too slow to respond at times, try remagnetizing it again.

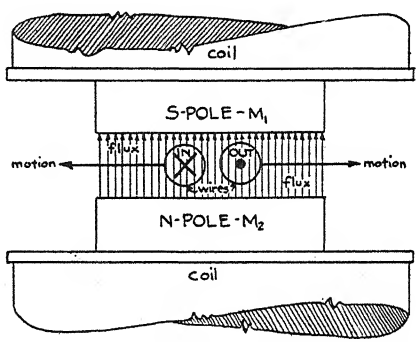


FIG. 60. Direction of induced current in a wire.

Right-Hand Rule for Generators. From these experiments certain facts may be noted as always true for a conductor cutting through flux. Record should be made of these as shown in Figure 60. Note that, in these drawings, the wires are shown as circles, as if representing a section of the wire between the poles. The wire carrying current **out** of the page is shown as a circle with a dot in it, as the point of an arrow coming **out** of the page. The wire carrying current **into** the page is shown as a circle with a *X* in it, as the tail of an arrow going **into** the page (see Fig. 60). Examine the right-hand rule illustrated in Figure 61, as it indicates how to determine, without experi-

ment, the direction of the induced current, when the flux direction and motion of the wire are known.

Notice that the thumb, and first and second fingers of the right hand are held at right angles to each other. When so held, the various fingers may be used to show the direction of the wire motion, the direction of the flux that is being cut, and the direction of the induced current set up in the wire. In other words:

Thumb points in the direction of **motion** of the wire cutting the flux.

Forefinger points in the direction of the flux cut (N to S).

Center finger points in the direction of the induced **current.**

As an aid in remembering this rule it should be noted that forefinger and flux both begin with "f"; and center finger and current both begin with "c." Figure 61 shows the rule applied to the right-hand wire in Figure 60. Check the rule on the other wire shown in Figure 60, and against the results of Experiment 28 and especially Experiment 27. The rule given here is absolutely correct and should check with the experimental results.

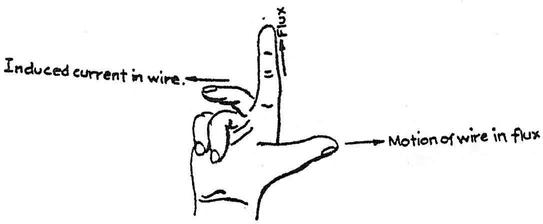


FIG. 61. Right-Hand Rule for generators.

70. How the Flux Cut Affects Induced Current. The tests made in Experiments 25, 27, and 28 give a very good idea about how the amount of flux cut by a wire governs the amount of voltage induced in the wire.

It is not difficult to see that cutting more lines of flux per second will cause a greater generated voltage in the conductors. Doubling the amount of flux cut per second will double the generated voltage. This can be done in two ways, one of which is to increase the magnetic flux by increasing the current in the

magnets. Cutting down the flux to 1/3 the original lines would cut down the generated voltage to 1/3 as much as at first.

71. How the Speed Affects Induced Current. The other way to increase or decrease the amount of current generated also may be noted in Experiments 25, 27, and 28.

By changing the speed of the wire through the flux being cut, the generated voltage may be changed. Doubling the speed, without changing the flux, will double the induced voltage. Cutting down the speed to 1/3 the original amount will, of course, cut down the induced voltage to 1/3 as much as at first.

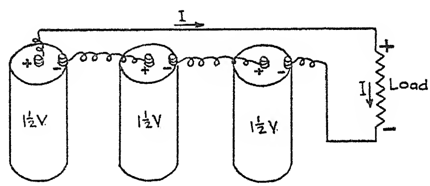


FIG. 62. Series connection for greatest voltage.

72. Connections for Most Voltage. Connecting generators or batteries in series will produce the greatest voltage, provided one precaution is observed. Always connect the units as shown in Figure 62, with + to — connections so the current never flows the wrong way through any one unit. "B" batteries for radio use are wired this way, with all cells in series.

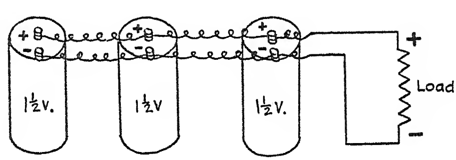


FIG. 63. Parallel connections for greatest current.

In a series battery circuit, the voltages add. For example, in the circuit in Figure 62, the total voltage will be about 1.5×3 or 4.5 volts. The current through each cell will, of course, be the same.

73. Connections for Most Current. Paralleled batteries or generators produce the greatest current. Figure 63 shows the

details of such a parallel connection for dry cells. Here each of the three cells need supply only 1/3 of the total current drawn. Thus, a group of paralleled batteries will last much longer on a heavy drain service than would three individual cells used one at a time.

In a parallel battery connection, always be sure to connect all + terminals together, and all — terminals together, as shown in Figure 63.

In a parallel battery circuit, the voltage of all batteries must be the same. For example, in the circuit in Figure 63, the total voltage on the load will be the voltage of any individual cell, which is about 1.5 volts.

NOTE: Parallel-series combinations of batteries may be used to supply both heavy currents and high voltages when needed.

74. Testing a Battery. The amount of energy in any dry cell can be easily wasted by bad testing methods. The customer wants to know the condition of the battery he is buying, yet he does not want to buy a badly used or much tested battery. How can a battery be rightly tested then? Following are several rules that are easy to understand and remember.

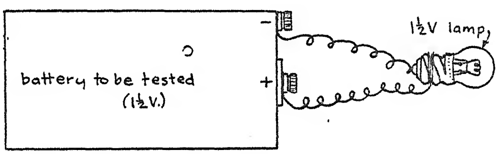


FIG. 64. Testing a dry cell with a 1.5-volt lamp.

Storage Batteries:

1. Never test a storage battery with an ammeter. The meter will be ruined by the enormous current drawn.
2. Use a hydrometer to measure a storage battery's charge.

Dry Cells (all kinds):

1. Never use an ammeter to measure the energy of a dry cell. This merely wastes amperes that cannot be regained.
2. Use either a voltmeter to measure the correct rated voltage of the cell (1.4–1.5 volts per cell) or a small flashlight

lamp across the battery, as shown in Figure 64. The lamp should have a voltage rating the same as the expected voltage of the dry cell — about 1.5 volts. If the lamp lights brightly, the battery is in good condition. Very short connections should be used from battery to lamp.

75. **Dangerous Voltages.** Any d.c. or a.c. voltage over 100 volts is somewhat dangerous to handle without adequate insulation. The greater the voltage, the more dangerous. A.C. voltages are about 1.4 times as dangerous as d.c., because a.c. really reaches a voltage 1.4 times as great as a d.c. voltage of the same rating.

It is dangerous to uselessly expose oneself to electric shock, no matter how mild the shock may be. Several rules for safety should be set down here as sensible precautions:

1. Never handle bare conductors having voltages above 50 volts, either a.c. or d.c.
2. Never change house-circuit fuses or make any house wiring changes with the main switch closed. Always open this switch first; do not close it when anyone may be working on the lines.
3. Leave all fallen wires alone! All fallen wires are not "live" wires; but being safe is better than being "wise" but dead! Let trained linemen handle all cases of fallen lines of any kind.
4. Never fly kites near high-voltage lines. Every year such kite flying results in some electrocutions.
5. Keep hands off automobile ignition circuits. Leave such work to those who know how to be safe from dangerous shock.
6. Never touch metallic electric appliances (irons, washers, toasters, etc.) when also touching either water or gas ("grounds") pipes. Frequently people are electrocuted in the bathroom by touching a poorly insulated lamp socket or switch while in contact with water fixtures such as the tub or the washstand.

Play Safe! Nobody was ever sorry for having used safety measures. Only the fool takes undue and useless chances. Fingers are useless when burned off; eyes are useless when burned out. Play safe — treat high voltage with respect!

SUMMARY

High-voltage power lines usually have bare conductors, held by special disk insulators to prevent flashover.

Voltage sources are:

The battery — dry-cell type; storage-battery type.

The generator — wires whirled so as to cut lines of flux.

Polarity of a dry cell:

+ terminal is the carbon rod or the copper plate.

— terminal is the zinc can or plate which slowly dissolves.

Hydrogen gathers around the + pole of a battery, and cuts down the current delivered. Chemicals are placed in a commercial dry cell to absorb this hydrogen and prevent "polarization."

Charging a storage battery — run the current through the cells from + to —, backwards of the normal battery current. Keep the "gravity" of the electrolyte between 1150 and 1275.

The **Right-Hand Rule** for generators:

Thumb points in the direction of the **motion** of the wire.

Forefinger points in direction of flux being cut by wire.

Center finger points in direction of **current** induced in wire.

The **speed** of a wire cutting flux affects the voltage generated. Greater speed, greater voltage; less speed, less voltage.

The **flux density** affects the generated voltage in the wire cutting the flux.

Greater flux cut, greater voltage; less flux cut, less voltage.

Series batteries deliver greatest voltage.

Parallel batteries deliver greatest current.

Testing batteries: Never use an ammeter on any battery.

Storage batteries — use a hydrometer; proper operating range is between a "gravity" of 1150 and 1275.

Dry cells — use a good voltmeter (1.4 to 1.5 volts per cell), or use a standard small lamp of a voltage rating the same as the expected voltage of the battery.

Safe voltages — under 100 volts.

Dangerous voltages — all a.c. or d.c. voltages over 100.

PROBLEMS

Prob. 1. What must be the minimum spacing (inches) between bare conductors at 110,000 volts, to prevent an arc? Would damp air in the gap necessitate different spacing? How and why?

Prob. 2. Find the minimum number of insulator units, each rated at 15,000 volts, that should be used on a 230,000-volt transmission line. Does the insulation affect the cost of such a line? How?

Prob. 3. Why does lightning strike tall objects? How does Ohm's law answer this question? Explain.

Prob. 4. An insulator string is found to leak .00002 ampere at 5,000 volts. Find the resistance of the string.

Prob. 5. How much would the "leakage" be at 110,000 volts, with the insulator string of Problem 4?

Prob. 6. If Problem 4 insulator string is made of 15 units, find the resistance of each unit alone, and the voltage drop across it at 110,000 volts on the line.

Prob. 7. Why does a larger area of zinc in a dry cell permit a larger current to be drawn from the battery? Explain.

Prob. 8. If the internal resistance of a battery is known to be .01 ohm, and the current drawn is 35 amperes, find the internal-voltage drop.

Prob. 9. Find the external voltage of Problem 8 cell, if the "no-load voltage" of the battery is 6 volts.

Prob. 10. Why does the hydrogen gather at the + pole of a battery?

Prob. 11. Find the voltage needed to deliver 40 amperes to a starting motor having a resistance of .15 ohms.

Prob. 12. Suppose a loose battery terminal in Problem 11 adds .45 ohms, find the new current.

Prob. 13. What part of the whole battery charge is still left when a hydrometer reads 1215 in the battery acid?

Prob. 14. Diagram a storage-battery charging circuit to charge ten 6-volt batteries at once, series connected. What voltage would be necessary from the charger? (This is a common garage problem.)

Prob. 15. If a generator has a resistance of .15 ohms and delivers 48 amperes, find the internal-voltage drop at this load.

Prob. 16. If cutting a field of 550,000,000 lines in 5.5 seconds generates 1 volt, find the lines cut per second necessary to produce 1 volt.

Prob. 17. Based on the answer to Problem 16, find the lines necessary to be cut in 3 seconds to generate 1 volt all the time.

Prob. 18. Find the lines necessary to be cut in 1/10 second to generate 1 volt constantly.

Prob. 19. Why will a many-turn coil spun at high speed anywhere on the earth always generate a current in itself? (Principle of the earth-inductor compass.)

Prob. 20. Why make generators, when batteries can be made?

Prob. 21. Explain the R.H.R. for generators, with neatly drawn sketches.

Prob. 22. If M_1 and M_2 in Figure 60 are both made N poles, show the flux paths. Will the wire motion in such a field generate any current?

Prob. 23. Where does the energy in a lighted lamp really develop? What is the real source of all this power? (Think carefully, here.)

Prob. 24. Why does a coil of wire generate more voltage than a single conductor?

Prob. 25. Suppose a radio "B" battery has 60 small 1.5-volt dry cells in series. Find the total voltage of the unit.

Prob. 26. Find the number of 1.5-volt dry cells in series connection to deliver current at 22.5-volts pressure.

Prob. 27. On No. 6 (large) dry cells, the "load" should not exceed 5 amperes continuously at 1.4 volts. Find out how many cells, and in what connection, are needed to supply 30 amperes at 5.6 volts steadily.

Prob. 28. What voltage lamp should be used to "test" a 3-cell battery (series cells)?

Prob. 29. Suppose a 100-ampere ammeter has a resistance of .02 ohms. How much current would it have to "take" across a 6-volt storage battery? What would happen to the meter?

Prob. 30. Why should a washing-machine cord have the best rubber insulation and be kept in excellent condition?

Prob. 31. Find the total voltage of six 90-volt "B" batteries in series. Is this a dangerous voltage? Why?

Prob. 32. Find the current that the voltage source in Problem 31 will drive through a hand-to-hand circuit of a man's body — about 200 ohms.

Prob. 33. Why is climbing power-line poles a dangerous thing to do? Explain.

Prob. 34. How much current will a 110-volt, 5-ampere electric iron draw on a 32-volt farm-lighting circuit?

Prob. 35. Find the voltage drop in a No. 0, copper, high-tension transmission-line wire 60,000 ft. long, when carrying 50 amperes.

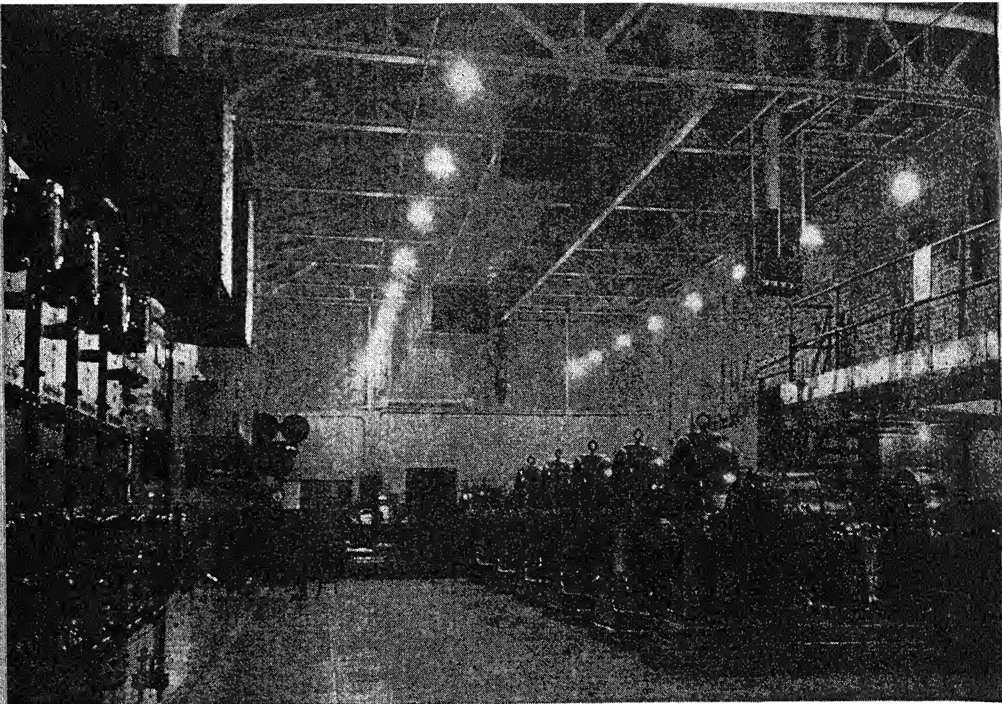
Prob. 36. What drop will occur if the wire of the line in Problem 35 is aluminum instead of copper at the same load?

Prob. 37. To have the same "drop" as the copper line has in Problem 35, what size aluminum wire must be used? (How many No. 0 wires in parallel?)

Prob. 38. Experiment shows that, in a vacuum tube, electrons travel at a speed of 383 $\sqrt{E}$ miles per second, where $E =$ the applied voltage. Find the speed when E is 2500 volts.

Prob. 39. Why do electrons at extremely high voltages usually travel only in straight lines — "no curves, no coils, no bends"?

Prob. 40. What voltage lamps should be used in street cars with 660-volt trolley service, when the lamps are connected in series groups of three?



SEVEN WHIRLING CONVERTERS ORGANIZE THE ELECTRONS

In these fifteen-hundred-kilowatt units, electricity is changed into mechanical energy along the rotor shafts, and then back into electrical energy again in the generators. The alternating-current motors drive direct-current generators, to supply the trolley d.c. voltage to a large railway system.

These motor-generator converter units are extremely efficient, with full-automatic relay control and protection from all faults and load conditions. Sudden severe overloads are handled by these machines without trouble. Prolonged overloads merely make additional units automatically cut in on the line to divide the load safely.

The relay panels for these rotary converters are neat examples of the precision workmanship of the modern technical electrician. The whole station, with its automatic flashover and fire-quenching equipment for each converter, bears testimony to the designing ability of the engineer's brain behind it all.

Chapter V

DIRECT-CURRENT GENERATORS: ORGANIZING ELECTRONS

WITHOUT electric generators there would be little of the present wide use of electric power, with all its varied possibilities in the home, in the factory, in the store and office, and along the highways. Because the generator as a unit is so very important to the civilized world, it is worth a detailed explanation in this chapter. Generators are made in many types and sizes, but only the main ones in very common use will be discussed here. Enough details to be interesting, as well as a complete explanation of the simple generator, will be given.

77. Generating Current. In Experiments 25, 27, and 28 the general principle of a generator was shown. No matter how the particular machine may be made in any certain detail, all generators operate on a simple principle. Whenever a conductor (wire) is moved through flux lines, a current is generated in that wire. This is the only principle as yet known by which purely mechanical energy can be easily changed into electrical energy. Of course, this principle, when used, needs at least three main things as follows:

1. Some kind of engine, turbine, or other machine to turn the generator.
2. Coils, usually on an iron frame, to be turned by the engine.
3. A strong magnetic field in which to turn the coils or wires.

A simple experimental generator, that will induce enough current in its armature conductors to be measured on the galvanometer made in previous experiments, can be easily constructed. This model generator will show up all the important electrical details of much larger commercial machines. Aside from being an interesting experiment, this model will provide a good example of many of the more complex things about a real gen-

erator. Make a neat job of the model, and see how nicely it generates a direct current large enough to operate the galvanometer needle.

Experiment 30. Making a simple d.c. generator. Materials needed: materials for an electromagnet, as shown in Figure 67; some tin-can iron; a wooden spool; a rubber band; nails, screws, etc., for assembling parts on a wooden base.

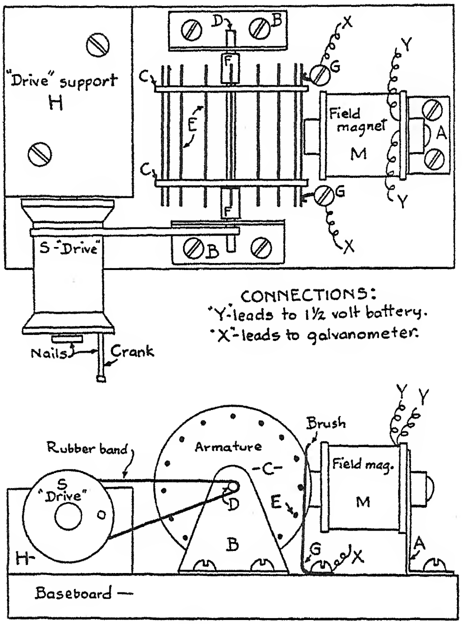


FIG. 67. A simple d.c. generator.

First, make a very strong electromagnet as was made in Experiment 5. Make a sheet-metal (tin) support bracket for the magnet *M*, as shown in Figure 67 at *A*. Do not mount the magnet on the baseboard yet, as the placement also depends on the armature and drive-pulley details. The electromagnet will be the generator's field.

Now the armature ("rotor" as it is often called) can be made. The only purpose of the armature of a generator is merely to hold the conductors and move them so they cut the lines of

flux of the field magnets. Of course, some kind of sliding contact (brushes) is needed to keep contact with the revolving armature conductors. Examine Figure 67 for details of the "armature" shown there.

Make two armature end pieces, *C*, as shown in Figure 67, about 1¾ in. in diameter, out of heavy cardboard. Punch holes in these cardboard disks with a large pin or needle, so a shaft, *D*, and copper wires, *E*, can be put in place. The shaft, *D*, may be a nail with the head cut off, leaving about 2½ in. of shaft. The armature wires, *E*, should be sixteen 1½-in.-long pieces of bare copper wire, about No. 18.

Adjust the assembled armature pieces on the shaft, in the middle. The armature wires, *E*, should protrude beyond the disks about ¼ in., as shown in Figure 67, to form the **commutator** bars. (The commutator is only a kind of sliding-contact connection to the moving coils of an armature.) A little glue may be used to hold all these armature parts securely in place on the nail shaft.

NOTE: Better results will be obtained from this model generator if the armature has a soft iron "core" or middle. This can be arranged by winding the space between the cardboard end pieces full of soft iron, such as "stove-pipe" wire or a strip of tin cut from a tin can. Do this before putting the copper conductors in place. Be sure no copper wire touches the iron core to cause a "ground" in the armature. Also, the iron core in the armature will add some weight and make the generator "run" easier.

Make two tin bearing supports for the armature, as shown by parts *B* in Figure 67. These bearings may be bent as shown, after carefully marking them exactly the same size, and drilling the holes for the armature shaft. Make these bearings of such a height that the armature center comes even with the magnet center, when mounted as shown in Figure 67, to make the best job.

Now arrange a "drive wheel" from a spool with a nail for a crank, as shown. A small block of wood may be used to hold the drive-wheel axle, which is a large nail or screw.

The parts may now be assembled on a baseboard, made of about 3 by 5 by ½-in. pine. Two short tin tubes or some small buttons or beads may be used to space the *B* bearing plates from the armature ends, as shown at *F* in Figure 67. See that

the armature shaft extends beyond the bearing enough to carry the rubber-band belt. The armature must turn quite freely.

Make two "brushes," *G*, out of stiff, bare, copper wire, held in place under two screws, as shown. These brushes are to lightly touch the armature wires as they cut the magnetic field flux of magnet *M*, when the armature turns.

To operate the generator, connect the magnet leads, *Y*, to a 1½-volt cell (direct current). Connect the leads from the armature brushes, *X*, to a galvanometer such as made in Experiment 12. A very sensitive milliammeter also may be used here.

When the crank is turned the armature should rotate rapidly, making the armature conductors cut rapidly through the pole flux of the field magnet *M*. These wires will then have a current generated in them, depending on the speed of the armature, the flux from the field magnet, and the direction of the armature (see Right-Hand Rule for a generator, Art. 69).

Experiment 31. Using the model generator. Materials needed: the complete generator of Experiment 30; a dry cell; a complete galvanometer or a sensitive milliammeter.

Be sure the compass needle of the galvanometer (Experiment 12) is very strongly magnetized, to insure the most sensitive operation. When strong enough, the compass needle will readily support a similar needle that is not magnetized.

Connect the field magnet, *M*, to the battery, by the leads, *Y*, as shown in Figure 67. Connect the armature leads, *X*, to the galvanometer or milliammeter, rigidly supported with a book or two.

1. Spin the armature. Which direction does the galvanometer needle move? How much does the needle move?
2. Reverse the armature direction. Which way does the needle move now? What does this indicate about the relation of the armature direction to the generated current direction?
3. Reverse the field leads, *Y*, to reverse the pole of the magnet, *M*. How does this affect the direction of the generated current?
4. Try the effect of speed change on the amount of power generated. If a milliammeter is used to measure the generated current, the exact amount of current at various speeds may be accurately noted and set down in the

notes of the experiment for future reference.

5. Does the "field current" affect the generated current in any way? Try this out with some kind of series resistor in the battery circuit, to vary the current to the *M* magnet.
6. Do all these results check with the Right-Hand Rule for generators? The magnet *M*'s polarity can be obtained for sure by using the compass needle as a test. Remember that like poles repel and unlike poles attract.

Keep this machine in good condition. Do not lose any parts. The parts will be useful in many more experiments on generators, as well as on motors, for both d.c. and a.c. It would be worth while to make some kind of neat storage box for all the experimental magnets, compasses, etc., which you have made thus far, to keep them together and safe from harm. Also keep a neat record of your experimental results. Try out your own ideas, too.

78. Producing Alternating Current. Strange as it may at first seem, all generators, whether d.c. or a.c., really generate only a.c. **inside** the armature. Examine Figure 68, and the reason for this will soon be seen.

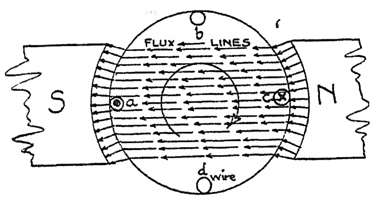


FIG. 68. All generators develop a.c. in their armatures.

In Experiment 27, it was shown that when a wire moves **upward** through flux, as at *a* in Figure 68, the current will flow **out** of the wire as shown. The very same thing is true of a wire on an armature, turning in a clockwise direction, as in Figure 68. If the flux (*N* to *S*) is as shown, by applying the Right-Hand Rule for generators, the current is seen to flow as shown at *a*.

When the wire comes around to place *c*, it will be moving **down** through the same *N–S* flux. But this reversal of the direction of rotation of the armature will also reverse the

current in the wire. Now the generated current will flow **into** the page in Figure 68, position *c*. Check this with the Right-Hand Rule for generators.

At positions *b* and *d*, the wire is moving **between** the flux lines, and not cutting any flux. So in these two places, of course, the generated voltage will be zero.

Restating these facts in table form, we have the complete story of what happens in the wire as the armature turns it through the magnetic flux:

Position of Wire	*Generated E.M.F.*
a	out of page (Fig. 68)
b	zero
c	into the page
d	zero
a	out of page
b	zero
etc.	etc.

This really means that the machine is generating an **alternating** current, a current that reverses its direction at regular times. Most homes are served by a.c. power lines that reverse this way **60 times each second.** Every generator produces an alternating current inside the machine's armature windings. Even d.c. generators really produce a.c., and change it over (rectify it) to d.c. by a commutator and brushes. Direct-current generators always have a commutator and brushes to do this. Alternating-current generators only need "slip rings," or two sliding contactors, to bring out the generated a.c. without changing it over to d.c. This is the chief difference between a.c. and d.c. generators.

79. **Why Slip Rings Are Used.** If the armature of a generator or motor is to rotate, and yet have some kind of constant electrical connection kept with it, then, of course, some special provision must be made for this contact.

Such special sliding contacts are by no means new. The trolley wheel of a street car is a common example of a sliding or rolling contact between a moving object and a power line.

On all generators and motors, some kind of contact must be

made to the moving armature. On a.c. generators, this is very easily done. Two insulated copper rings, called "slip rings," are arranged on the armature shaft, and are connected to the ends of the armature winding. Now, two insulated "brushes," usually made of carbon, are attached to the stationary frame of the machine, in such a way that the brushes always touch the slip rings as the armature revolves. In this simple way, the generated current is delivered out of the moving armature of the machine.

Slip rings do not change the armature connections as the armature turns around. Therefore, whatever kind of current is generated in the armature, that same current is **brought out** of the armature to the main line. Because all generators really develop only a.c. **inside** the armature windings, then all generators that use slip rings to connect the armature deliver **alternating** current, and so are called **alternating-current generators**, or **alternators** for short.

80. **Changing from A.C. to D.C.** Not all generators are made with just slip rings to deliver alternating current to the load. Most elevator and street-car motors must have a direct-current source of power, as well as many other direct-current uses equally common in industry. So some means had to be developed to change the a.c. to d.c. in these cases.

This changing, called **rectifying** the a.c., can be done in many ways, some of which require special tubes as used in modern radio sets (rectifier tubes). Sometimes a special device as that used for battery-charger rectifiers (vibrating or electrolytic rectifiers) is required. These types will be discussed later. Just now, the simplest kind of rectifier in common use will be discussed.

The **commutator** on a d.c. generator is a very simple automatic switch designed to change the a.c. in the armature to the desired line d.c. The commutator on a d.c. motor is there to automatically change the line d.c. to the a.c. necessary for the armature power.

In very simple words, any commutator is merely a switch, operated by the armature itself in turning. This switch connects and reconnects the armature turns or coils to the line in such a way that the generated power always flows the same direction in the line to the load, thus being d.c. power.

Examine your model generator as made in Experiment 30 and shown in detail in Figure 67. Notice that, as each armature bar comes to a place, it cuts the field-pole flux in a certain direction; the brushes at that instant contact that bar and connect it to the main line. At just the right instant, as the armature turns around and a new bar is cutting the flux of the field pole, the commutator and brushes have automatically connected in the new bar and disconnected the first one from the circuit.

On large d.c. machines the same commutator action takes place, in exactly the same way as on this model d.c. generator, producing d.c. in the line instead of a.c. as would be the case were slip rings used instead of a commutator. The basic idea of any commutator is merely that of an automatic switch.

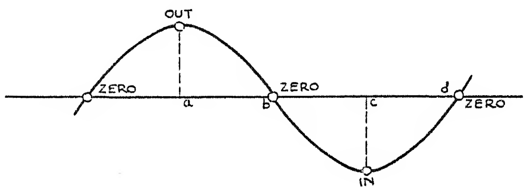


FIG. 69. The graph of an alternating current.

81. The Commutator as an Automatic Switch. Examine Figure 68 again. Notice that when the wire turns from place *a*, to *b*, to *c*, to *d*, and to *a* again, and so on, an **alternating** current is generated. This whole story can best be shown by a graph, as in Figure 69. In this graph, which refers also to Figure 68, the + side of the curve represents current **out** of the page in Figure 68, and the — side of the curve represents current **into** the page in Figure 68.

A **direct** current is one that never reverses direction as does an alternating current. The job of the commutator on a d.c. generator is to change over the a.c. actually generated in the armature to the desired d.c. at the terminals of the machine. Figure 70 shows graphs of the a.c. and changed-over d.c. of a standard d.c. generator.

Figure 70 shows that loop number 2 of the a.c. curve has been "turned over" in the d.c. curve, to keep the current flowing always in the same direction in the wire of the line. This is

what the commutator (or automatic switch) must do on all d.c. generators. But the job is not so hard as it at first may seem.

Merely reversing the connections to the armature coil at the

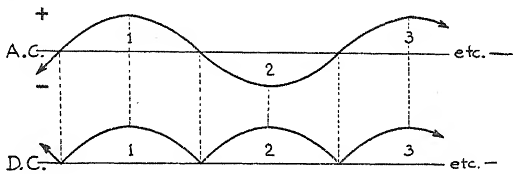


FIG. 70. A.c. and d.c. in a d.c. generator.

right instant will reverse the current flow to the main line. If the brushes and commutator bars are so arranged that they break and reverse the connections automatically, at exactly the right instant, then the a.c. from the armature coils will be changed to d.c. for the line.

The scheme of all alternating-current generators is shown in Figure 71, which illustrates a simple 2-pole generator with two slip rings and brushes at X and Y to deliver the current out of the armature. Of course, a real machine has many more turns on the armature than Figure 71 shows, but the idea is the same, nevertheless. The slip rings are merely a device to keep a steady electrical contact with the moving armature coils.

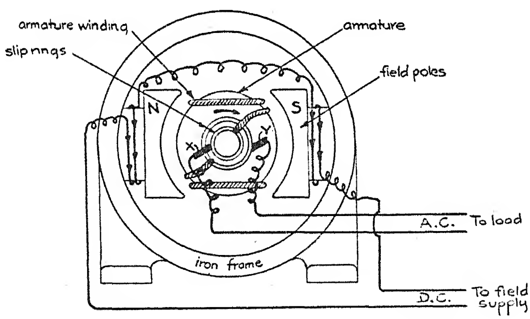


FIG. 71. The scheme of a.c. generators.

All direct-current generators are exactly like alternating-current generators, except for one detail. The d.c. generator has

a commutator, as shown in Figure 72, that acts as the necessary automatic switch to change the a.c. over to d.c. The curves in Figure 70 show what this change means, electrically, and Figure 72 shows how to do it. Notice that the two pieces (bars) of the commutator are insulated from each other, and turn in contact with the brushes X and Y. At just the right instant, when the generated voltage is about to reverse because the armature coil has turned 180 deg. (half way) around, the commutator bars reverse their connections with the brushes X and Y. Then the new "loop" of the curve (Fig. 70, d.c. curve, loop 2) will be "turned over," and the new surge of current will flow in the same direction as the last surge (loop 1). When all the surges (loops or humps) are in one direction, the line current from the generator will be a pulsating direct current. Figure 72 shows the details of the commutator on such a d.c. generator. Of course, the speed of the commutator (automatic switch) will always be just right, because it is firmly attached to an insulated ring on the armature shaft.

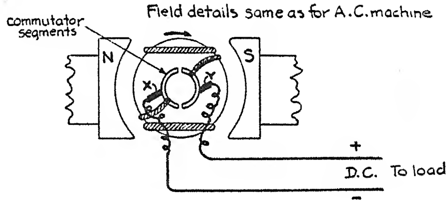


FIG. 72. The scheme of d.c. generators.

Large d.c. generators have many armature coils, and so must have many bars in their commutators. But the basic idea of the commutator as an automatic switch to change the generated a.c. to d.c. is the same.

82. The Parts of a D.C. Generator. While the sizes of generators vary widely (usually rated in horsepower and watts) the general construction details and materials are similar in all sizes. The following list of generator parts covers most d.c. generators:

These parts are all shown in Figure 73, numbered as in Table XV. Some unimportant details have been purposely left out of

this drawing, to show up the more important parts as listed. The machine shown has 4 sets of brushes, although only two sets are in a visible position. The end frame hides the other two sets.

TABLE XV. D.C. GENERATOR PARTS

Part	*Material*
1. Machine frame	usually cast iron
2. Field poles	soft iron or soft steel
3. Field coils	copper wire, insulated
4. Armature	laminated soft iron
5. Armature winding	copper wire, insulated
6. Brush assembly	carbon blocks on bronze springs
7. Commutator	copper bars or segments
8. Shaft	steel
9. Bearings	brass or bronze; ball bearings
10. Terminal pothead	metal to protect connections
11. Driving pulley	wood or metal for belt or chain

Larger machines have many refinements that the smaller generators do not have, such as high-pressure oil bearings, spring-cushioned brushes, and fire-extinguishing gas chambers to care for emergencies that cause fire in the machine windings. But large or small, simple or complicated, all d.c. generators operate

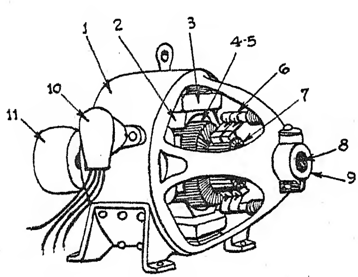


FIG. 73. A four-pole d.c. generator.

on the same basic principle, and all are made of similar details. When you have examined one d.c. generator or motor, you have really "seen them all," in a way.

Watch one of these mighty powerhouse generators as it spins

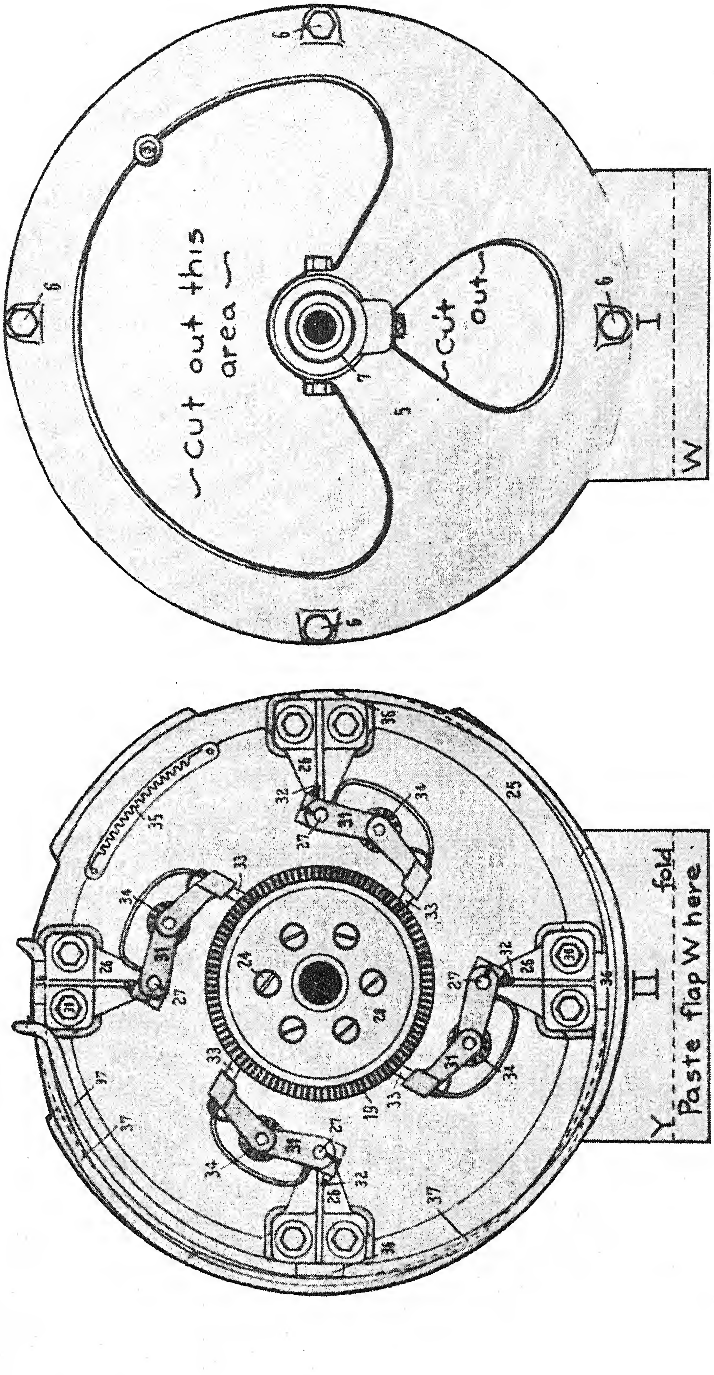


FIG. 74. Sections of a 4-pole d.c. machine.

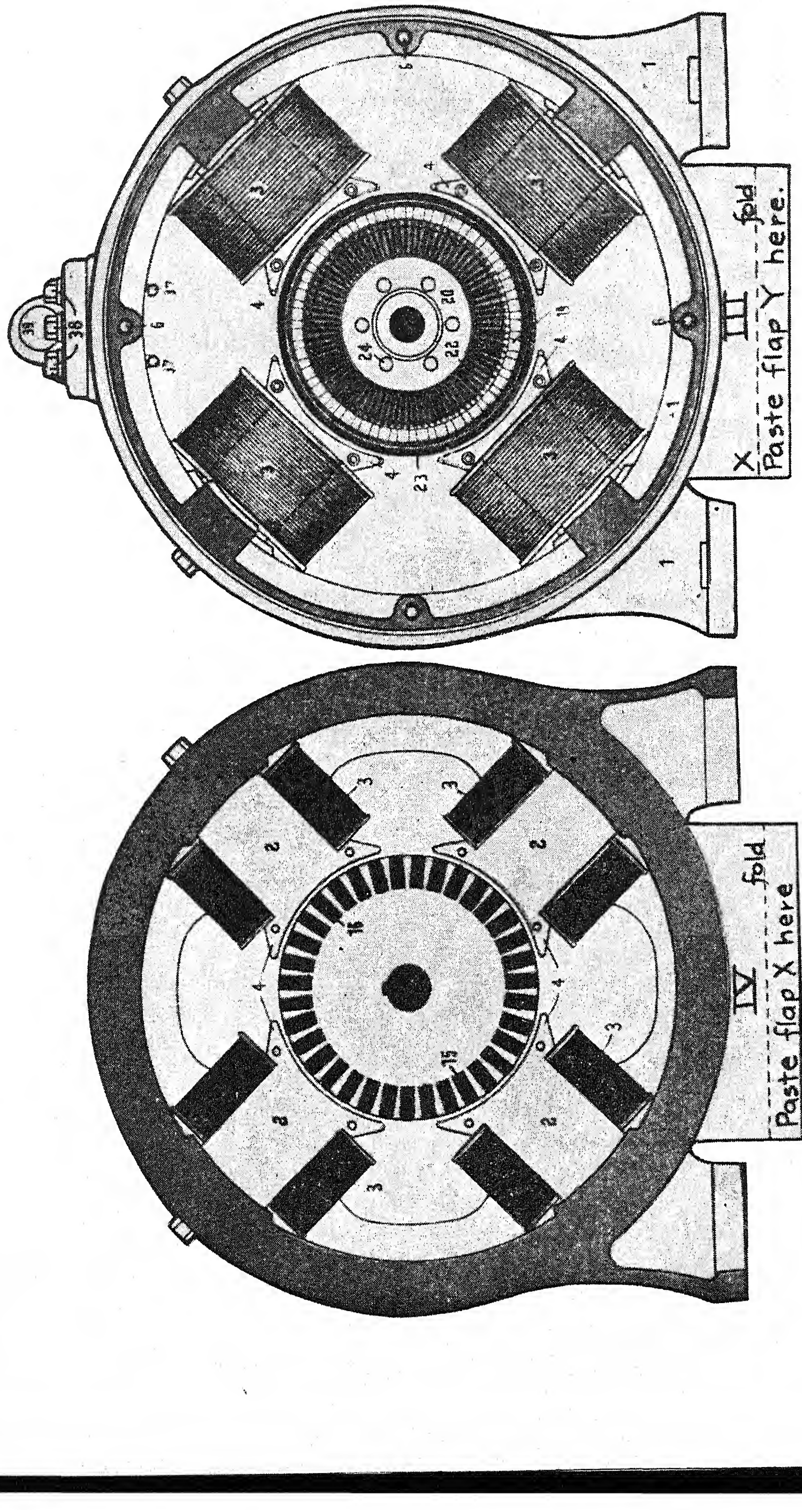


FIG. 74a. Sections of a 4-pole d.c. machine.

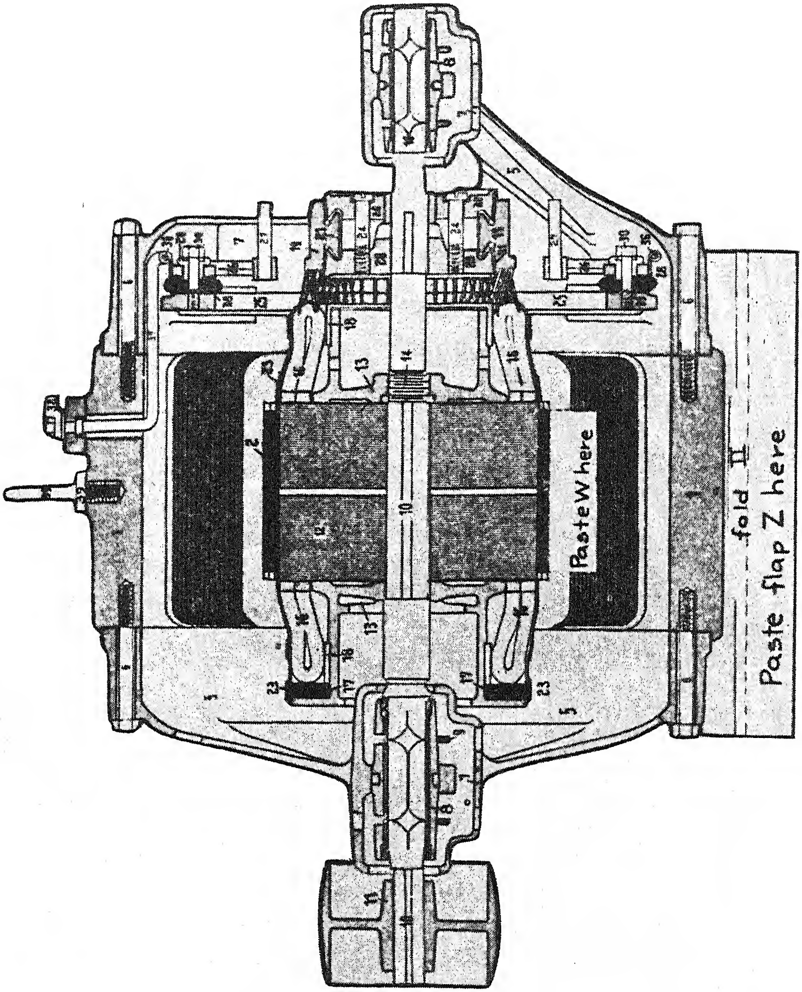


FIG. 75. Another section of a 4-pole d.c. machine.

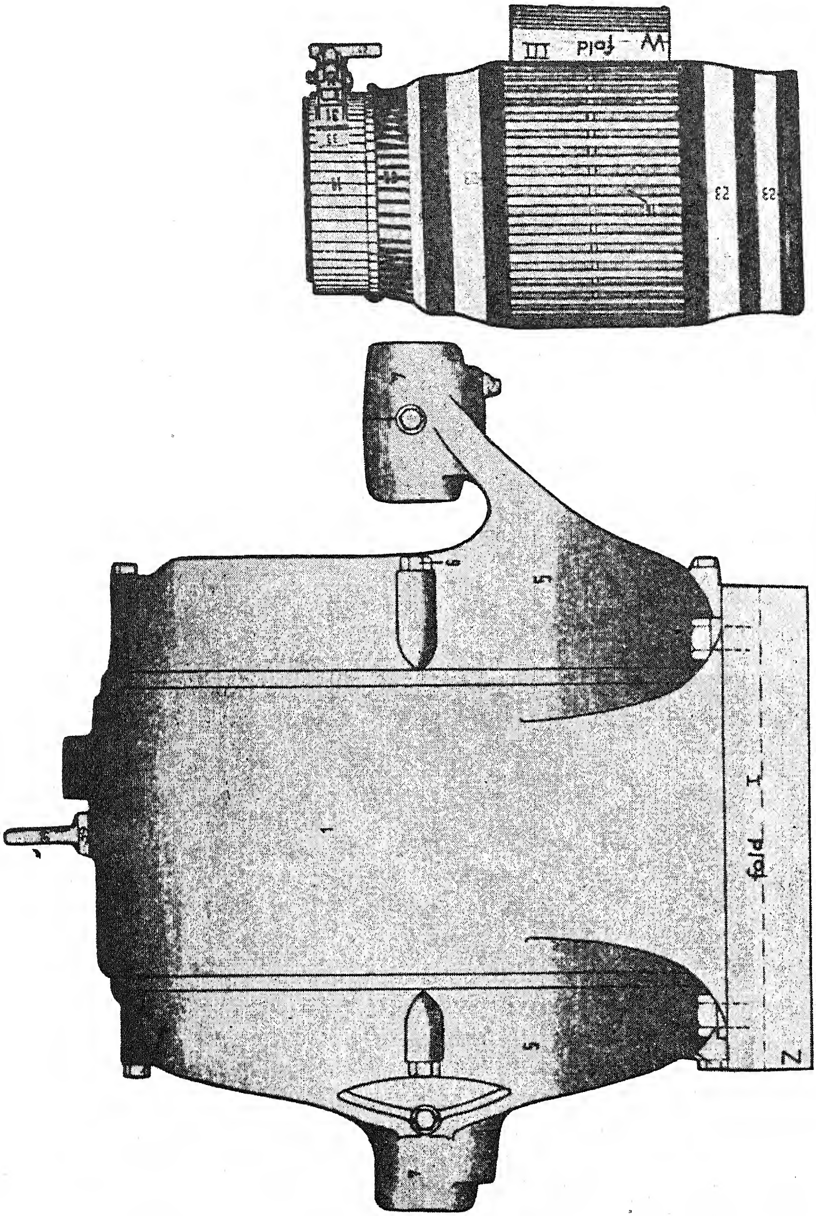


FIG. 75*a*. Two more sections of a 4-pole d.c. machine.

to a tune of deep-toned music of modern industry. See the heavy armature steadily whirl past the densely fluxed poles of the field. Notice the large brushes, with their tiny sparks streaming out behind and around the polished commutator. Feel the floor beneath you tremble as the machine "carries on" under a severe overload, with a steady throb and the pulse of a giant, as if it has a brain of its own that demands constant loyalty to the job of supplying power, against all odds. Get the thrill of knowing all about the "inside workings" of the machine; find out how it operates! It will be well worth all the trouble and time spent. Go out of your way to watch a big generator at its job.

Experiment 32. Making "sections" of a 4-pole d.c. machine. Materials needed: thin paper (tracing paper); drawing compass; straightedge (ruler); pencils or pen and ink (India ink, such as is used in drafting, will be best); drawing paper; colored pencils or paints.

If this experiment is worked out neatly, it will give you a good idea of just how the parts of a typical d.c. generator or motor look and are assembled. Figures 74 and 75 show the construction of a 4-pole d.c. generator (also a 4-pole d.c. motor) as it would be explained by a draftsman or engineer. Table XVI lists all the parts shown in these cross-section views, giving the name of the part, its materials, and its use in the assembled machine.

With the use of good drafting methods (dividers or scale methods of copying) you can make drawing-paper copies of all these sections, coloring, labeling or numbering them, and pasting them all together into two sets.

Make neat copies of these sections, so every detail is as clear as it is in Figures 74 and 75. Then color the parts, if you care, to make them stand out well, as they do in the pictures shown. **Do not mar this book in doing this job.**

Then carefully cut out the drawings made, leaving tabs for pasting them together, as shown. Be sure to paste them in the proper order, so that when turned down as book pages, you see further back into the machine with each section.

Put these two section assemblies (end and side sections) into some kind of heavy drawing-paper folder. Neatly label the folder title something like this:

Cross-Section Views
and
List of Parts
of a
4-Pole D.C. Machine

List the parts of the machine, as shown in Table XVI, on one side of the folder, opposite the two section assemblies. Make your folder a real workmanlike job, fit to be shown to your older electrician and engineer friends.

TABLE XVI. PARTS OF A 4-POLE D.C. MACHINE

No.	*Name of Part*	*Remarks*
1	Machine frame	cast iron or steel; carries machine "feet" or base
2	Pole cores and shoes	laminated iron, riveted or bolted together
3	Pole windings (coils)	copper wire, insulated
4	Pole-shoe plates	soft iron, riveted or bolted to laminations
5	End frames	cast iron or steel; carry armature bearings
6	Assembly bolts	steel, with nuts; to hold on end frames
7	Bearing housings	part of end-frame castings
8	Bearings	bronze; usually arranged for oil lubrication
9	Oil-picking rings	brass; to help keep bearings lubricated
10	Shaft	forged steel; machined and polished
11	Pulley	cast iron; for leather belt, when used
12	Armature core	laminated iron; punchings; each "varnished"
13	Armature ends	cast iron; to clamp armature laminations
14	Shaft threads	cut on end plate 13, also; to rigidly clamp armature
15	Armature coils	heavy copper bar, taped and impregnated
16	Armature coils	heavy copper bar, taped and impregnated
17	Armature pads	bakelite or asbestos; to help hold coils in line
18	End insulation	empire cloth or "fish paper"; to help insulate coils
19	Commutator bars	copper; held in place with clamps; insulated (sometimes molded in place)

20 Commutator clamps	iron; to clamp commutator bars in a ring
21 Bar insulation	special empire cloth, "fish paper," or bakelite
22 Commutator connections	copper — leads from armature coils to bars 19
23 Banding wire	steel; to hold armature coils securely in place
24 Commutator bolts	to clamp in commutator bars
25 Brush ring	steel; to support brush assemblies
26 Brush brackets	steel; to carry part 27
27 Brush pins	steel; to carry brush assemblies on brush ring
28 Insulating bushings	bakelite; to insulate brushes from part 25
29 Insulating bushings	bakelite; to insulate brushes from part 25
30 Bolts	steel; to attach part 26 to part 25
31 Brush arms	brass; or bronze; to hold brushes
32 Brush bolts	steel; to clamp brush assemblies to part 27
33 Brushes	carbon blocks; copper plated, usually
34 Brush-tension adjuster	spring arrangement to keep brushes on commutator
35 Brush-position adjuster	steel; rack and gear to adjust brush ring
36 Field connections	heavy copper or brass tubing for part 37
37 Field connections	heavy copper wire, insulated
38 Connection lugs	heavy copper lugs; terminals of the machine
39 Crane ring	forged steel eye; to facilitate handling

Experiment 33. Making a paper schematic 2-pole d.c. machine. Materials needed: heavy drawing paper; drafting instruments; thin paper, for tracing a book drawing; paste or glue, scissors or razor blade.

Real machines, no matter how far dissembled, do not show such invisible things as flux lines in the various parts or currents in the wires. But with a little work you can make a paper model d.c. machine that does show these things. The finished model should look like the sketch in the corner of Figure 76.

Make a very careful copy, on drawing paper, of all the parts shown in Figure 76. Use tracing paper, if you cannot do it by drafting methods, using dividers on a ruler. But be sure not to mar this book in doing the copying job.

On your drawing-paper copy, mark all the flux lines, coil

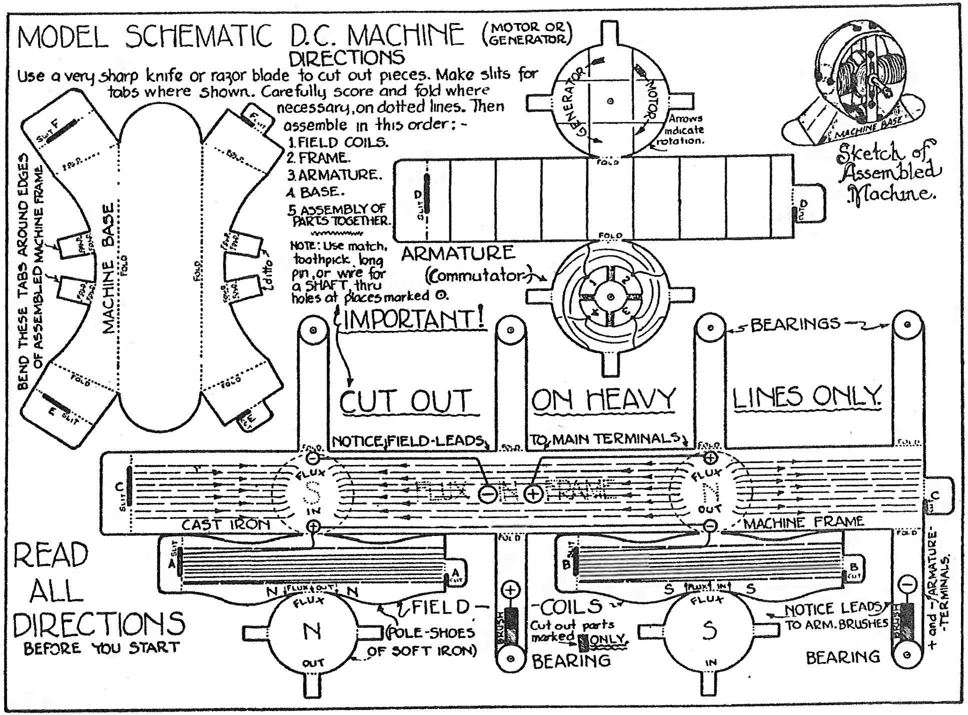


FIG. 76. Schematic 2-pole d.c. machine.

windings, armature windings, etc., as shown in the details in Figure 76.

Following the directions given in Figure 76, assemble these parts to the finished model, as shown in the sketch. A toothpick or match stem may be used as a shaft. The commutator bars will show up in the space cut out under each brush.

The parts may be pasted together, if a more permanent job is desired. To more closely resemble a real machine, these parts also may be colored. Compare this machine to the sections made up in Experiment 32. Of course, this paper model is not an exact representation of a real machine in all respects. It is primarily a model to show up flux, current, and technical operation details that are not visible on a real machine.

Check this machine as a d.c. generator, by using the Right-Hand Rule for generators on it. When turned as marked on the armature, for a generator action, does the generated current actually flow out at the + brush? Check this carefully.

Why must the machine frame be made of iron instead of such metals as brass or aluminum? Would the use of these other metals in any way change the field flux? Why?

Imagine the necessary field connections on this paper model to make it a **shunt** machine. Check the *N* and *S* poles with the coil windings, using the Right-Hand Rule for a coil. Why are the pole "shoes" curved to come close to the armature?

In one revolution of the armature of this model, how many changes in current occur in each armature wire?

Keep this model handy, as you study further about generators. It will also be a great help to you when studying about d.c. motors, in Chapter VI.

83. The E.M.F. of a Generator. The generated voltage in any particular machine depends on several things, all considered at the same time. These things are explained in the following paragraphs. Check them carefully against the facts you learned from your experiments with the model generators previously made.

1. **Turns of Wire on the Armature** and how these turns are connected (series or parallel) greatly affect the amount of voltage generated. Suppose each armature turn on a certain generator actually develops 1.5 volts, and that the winding has a total of 400 such turns in it. Then,

if the turns are all in series, the total generated e.m.f. (voltage) will be (1.5)(400) or 600 volts.

But if the turns were all in parallel, then the total voltage generated would be only 1.5 volts, with 400 times the current of a single turn as the total generated current of the machine.

2. **Speed of the Armature** directly affects the generated e.m.f. (voltage) of the machine. Suppose at a speed of 1800 r.p.m. (revolutions per minute) a certain generator develops 150 volts. Then at 900 r.p.m. (half speed) the developed voltage would be only 75 (half the rated voltage of 150). And at 3600 r.p.m., the voltage would be 300.

   The reason for all this is simply that the induced voltage in a wire depends on how much flux the wire cuts through in one second.

3. **Field Strength** also affects the generated e.m.f. Suppose that, with each pole of a large generator's field supplying 5,000,000 lines to the armature, the generated voltage is 250 volts. Then to produce 500 volts, with this machine running at the same speed as before, the fields will each have to supply **twice** the lines they did before, or 10,000,000 lines of flux. A decrease in the flux of each field pole to 2,500,000 lines will lower the generated voltage to 125.

To summarize, then, we can say that these are the things that greatly affect a generator's voltage:

1. The construction details of the generator — especially the number of turns on the armature.
2. The speed of the armature — which, of course, means the speed of the driving engine or turbine. Some kind of speed control (governor) is usually required to keep a steady speed of the driving engine or turbine, when a constant voltage is demanded.
3. The strength of the field poles — which can be controlled by a rheostat in the field supply circuit. More field (magnet) current will give more lines; less field current will cause a decrease in pole flux. These three factors are kept in mind always by the draftsman, the design

engineer, and the manufacturer of all generators. Incidentally, the same three factors will similarly affect motors, which are very similar to generators.

84. **Delivered Voltage of a Generator.** The voltage that a particular generator will actually deliver to the load is always a little less than the **generated** voltage in its armature. The reason for this again brings Ohm's law into use.

Suppose, for example, a certain generator armature actually generates 150 volts. Now suppose the armature resistance of this machine is 0.2 ohm, and the machine is delivering 30 amperes from its armature. These facts are shown in Figure 77.

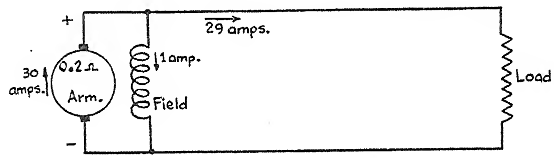


FIG. 77. Terminal voltage is always lower than generated e.m.f.

The "armature drop" can be found, using Ohm's law:

$$\text{Armature voltage drop} = I_A R_A = (30)(.2) = 6 \text{ volts.}$$

Therefore, the **terminal voltage** will be 6 volts less than the actual generated voltage:

$$E_T = E_G - I_A R_A;\ E_T = 150 - 6 = 144 \text{ volts.}$$

It can be easily seen that the greater the armature current in a generator, the less the terminal voltage will be, unless some special method is used to offset the "armature drop." Some generators take care of this "drop," by automatically strengthening the field flux. Such d.c. generators usually are **compound** generators, with two field windings, one in parallel with the armature and one in series with the armature. These machines will be studied later, as a matter of practical interest.

Just remember, here, that the delivered **(terminal)** voltage of a generator is lower than the actual generated voltage of the

armature by an amount equal to the armature current times the armature resistance:

$$E_T = E_G - I_A R_A;\ \text{or}\ E_G = E_T + I_A R_A.$$

Thus, knowing any 3 of the 4 terms involved, the other term can be easily found by simple arithmetic. For example, suppose that: the terminal voltage (E_T) must be 110 volts, when the current in the armature (I_A) is to be 40 amperes, and armature resistance is .3 ohms. How much must the generated voltage (E_G) be?

Solution: $E_G = E_T + I_A R_A$

$E_G = 110 + (40)(.3) = 110 + 12 = 122$ volts.

The 12 volts are lost in getting the generated 40 amperes out of the armature, which has a .3-ohm resistance. Of course, it is impossible to make a generator that has no armature resistance ($R_A = 0$), so therefore the terminal voltage (E_T) is always less than the generated voltage (E_G) when the armature current (I_A) is more than zero.

85. The Kinds of D.C. Generators. Generators are classed according to the connection of their "fields." D.C. generators are divided into two general classes:

1. **Separately excited generators** — where the magnet fields are either:

a) Permanent magnets, such as in the magneto type.

b) Electromagnets, excited from a d.c. line or special field-supply battery.

2. **Self-excited generators** — where the fields always are electromagnets, "fed" from the armature of the generator itself, as shown in Figure 77. This generator is made in two common types:

a) **Shunt** (or parallel), where the fields are connected in parallel with the armature (Fig. 77).

b) **Compound,** where both a parallel-connected and a series-connected set of field coils set up the field flux.

Separately excited generators (except magnetos) are rarely used, and so will not be discussed in this text.

86. The Shunt Generator. The shunt type of d.c. generator is commonly used in industry, and therefore will be discussed.

Figure 78 shows a diagram of a shunt generator. Notice that the armature supplies current to both the "load" circuit and the machine field circuit. The two field coils are connected in series, and then are connected "across" the armature brushes, or in parallel with the armature. This is the connection of all shunt generators. A more easily read type of diagram which shows the same idea as Figure 78, but is simpler to draw, is shown in Figure 79. Both of these diagrams show the shunt fields of the generators arranged with a rheostat so their current and magnetic flux can be adjusted as desired.

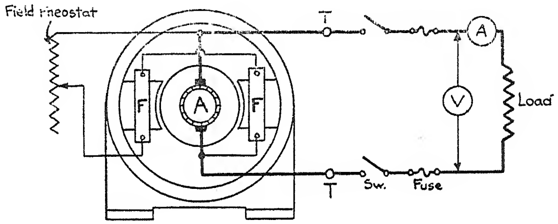


FIG. 78. The shunt generator.

The examples given in Article 84 refer to this type of d.c. generator, where E_T is always less than E_G, by the $I_A R_A$ drop in the armature. The field current in shunt generators is usually very low, compared to the total armature current, and does not impose too much on the armature.

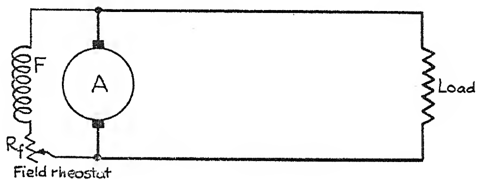


FIG. 79. Simplified diagram of the shunt generator.

By placing a **rheostat** (R_f) in the field circuit of this generator, the field current can be adjusted as desired by the operator. A change in the field current will change the field flux, and thus change the generated voltage of the machine.

To operate a shunt generator, a few rules should be observed:

1. Check all connections, to make sure there are no "shorts" or improper connections. "An ounce of prevention, etc."
2. Be sure no load is connected to the generator.
3. Start the machine; bring it up to speed.
4. Adjust the field rheostat until the terminal voltmeter shows that the generated voltage is what it should be.
5. Close the main switch.
6. Readjust the field rheostat until the voltmeter again shows the rated load voltage of the machine, as marked on its nameplate.
7. Be sure the machine does not run too hot, under load. Keep bearings well oiled. (Never oil brushes.) Disconnect the machine as soon as possible in case of any trouble.
8. To stop the generator, first open the main switch to cut off the load; then stop the driving engine.

These simple precautions, if followed, will give any generator a longer life than is usual under careless handling. A generator, like any other complicated machine, needs sensible care and handling for best results. Motors and generators are by no means "foolproof," but must be carefully set up and used, if good operation is desired of them.

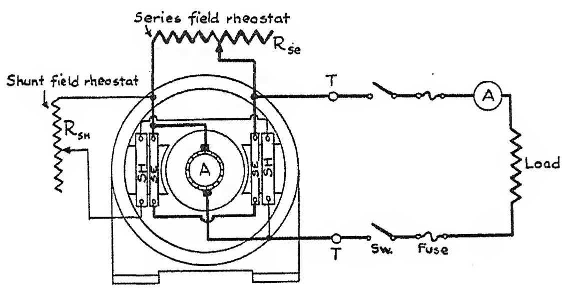


FIG. 80. The compound generator.

87. **The Compound Generator.** Compound generators have two sets of field coils, one in parallel (shunt) with the armature, and another connected in series with the armature to the load.

This extra set of field coils is called the **series field**. The

purpose of the **series** field coils is to overcome a defect of a straight shunt generator. Under heavy load, a shunt generator tends to have a lower terminal voltage than under a light load. These generators would never do, then, for such work as lighting houses, where a constant or steady voltage is desired, no matter how slight or great the load. Figure 80 shows a **compound** generator circuit, and a simplified diagram of this machine is shown in Figure 81.

Notice the location and purpose of the rheostats. They are merely to adjust the amount of current going through each field, and thus control the field flux and the generated voltage. Simplified diagrams are easier to make and read, and give just as much information as do the complex machine diagrams, as the one shown in Figure 80. But be sure, when using a simplified diagram, that you keep in mind the real "layout" of the actual generator or motor which is represented. Keep in mind the number of field poles, each wound and set in place in an iron frame. See in the diagram symbol for the armature, all the details of a real machine armature, with its commutator and brush connections. Then a simple diagram will become a very useful "tool" to you, helping you to visualize a complex machine in an easy manner.

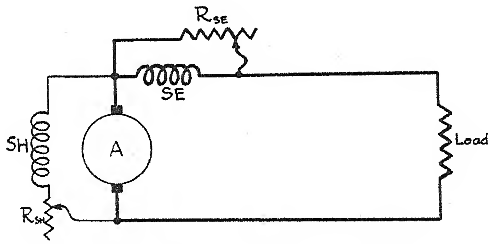


FIG. 81. Simplified diagram of the compound generator.

Returning to the purpose of the series field in the generator, examine the diagram in Figure 81. Notice that the load current must pass through the **series** field, a few turns of very heavy copper wire on each pole piece, as shown in Figure 80. This will give some additional flux to the fields, depending on the amount of current which the **load** draws through these **series** windings.

Remember that, with only a **shunt** generator, the voltage tends to drop off as the **load** increases. But now, with these extra **series** windings helping out, the terminal voltage can be kept fairly constant, regardless of how much current the **load** draws. This constant-voltage feature of all **compound** generators makes them very useful on circuits supplying any power and lighting lines, where the load varies from hour to hour but the voltage must remain the same.

The operation of **compound** generators is the same as for **shunt** generators. The same general precautions should be kept in mind. Refer to the last part of Article 86 for details.

88. Care of a Generator. Certain very important points should always be kept in mind about the care of generators of any type or size. It is good economy to observe these rules, for in the end such care pays large dividends. These points are:

1. **Commutator and brushes:**
   - *a*) Keep commutator clean and bright.
   - *b*) Never oil commutator or brushes.
   - *c*) Renew brushes (carbon) when badly worn.
   - *d*) Keep brush pressure springs tight.

2. **Bearings:**
   - *a*) Keep bearings oiled properly.
   - *b*) Renew bearings (bushings) when too badly worn.
   - *c*) Never operate the machine when the bearings are "burned" or too hot. Find and remedy the trouble.

3. **Operation:**
   - *a*) Keep field coils and armature clean of oil and dust.
   - *b*) Never overload the generator.
   - *c*) Never operate the generator to overheat it.
   - *d*) Never allow the machine to be short-circuited.
   - *e*) Always use correct value fuses in the main line.

89. Driving the Generator. Several common power sources are used to drive generators. Most of them are:

1. Steam engines.
2. Steam turbines.
3. Water turbines.
4. Wind wheels or propellers.
5. Gasoline engines.
6. Oil-burning Diesel engines.

The commonest one of these is the steam turbine, in regions where coal or oil abound. But, of course, in such places as Niagara Falls, or where a great dam can be built to impound water so it can be used as an artificial falls, the water turbine is used to drive power generators. Many farmers in areas where winds are strong and steady have built wind-driven generator outfits to produce light and a small amount of electrical power for farmhouse uses.

Of course, water power and wind power provide the cheapest form. Power companies using water wheels to turn their generators can supply power at a far cheaper rate than when coal is used as a fuel. The coal miner's wages figure in the cost of electric power where the power station is a coal-burning, steam-turbine plant.

For private use in isolated places (country and farm homes far off from "the beaten road") a gasoline engine can be used to drive the generator. But, in general, such a power plant will cost as much to operate as the electric-power rate in coal-burning power-plant areas. The private-plant owner also must make his own repairs and use his own time to care for all the details of his plant, such as the storage batteries, the engine, and the generator.

In some few cases, hand-driven generators are used. The country telephone line usually has a hand-driven magneto at each house, to supply ringing current to the bells on the line. (Figure 56 shows a typical magneto.)

There is no doubt that, in the city or urban districts, greater fuel economy has been gained by having a central power plant, modern in all details and well operated, than was possible in the days of individual electric plants. The present-day "January White Sale" custom of large department stores in big cities dates back to the days when these stores had their own power plants somewhere in a subbasement. Such plants were so dirty and inefficient that the annual sale of what had been nice white goods became necessary at midyear, to sell at a great discount the smoky, soiled materials.

The sale custom still persists, but it is now merely a custom, not a necessity. Central power plants use "smoke consumers" that even burn the smoke particles (good carbon), and the atmosphere of big cities is very much cleaner than it used to be.

The electrical engineer has had a large part in this change for the better.

90. Why the Armature is Laminated. The term *lamination* means a thin slice of the material. If you examine such devices as transformers, motors, and generators, you will notice that the iron armatures, cores, and frames usually are made up of "punchings," put together on some kind of bolts or shafts, to form a laminated field or armature. Why is this extra work done, when the parts could be made by casting the iron in a solid form, as needed? Well, there is a very good reason.

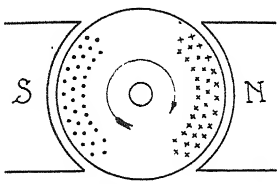


FIG. 82. Why the armature must be laminated.

Remember that, whenever a **moving** conductor (any metal is a conductor) cuts flux lines, a voltage is generated in that conductor. Now, suppose an iron armature of a generator is rapidly turning past heavy magnetic poles, as in Figure 82.

Even if this iron armature has no copper-wire coils on it, a voltage will be generated in the iron itself, as shown in Figure 82, according to how the armature turns. This useless current in the iron is called **eddy** current; it causes the iron to heat up, and in other ways hinders the action of the generator. Yet it takes energy to generate the current. So the problem becomes this: How can this useless eddy current be avoided?

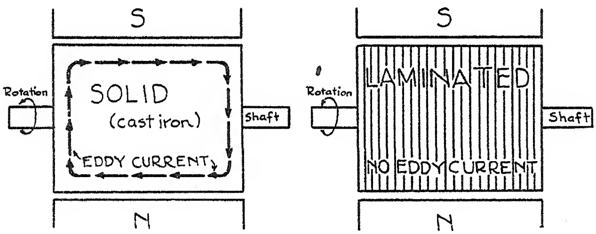


FIG. 83. Laminating the iron stops the eddy current.

If the armature is cut up into thin, insulated sections, or is made from varnished punchings, then the current cannot flow in the iron. Figure 83 shows such insulated laminations stop the

eddy current. Notice that in the solid iron piece, current can flow as shown, but in the laminated iron, the insulation on the punchings stops the flow of current.

The laminations must be insulated with shellac or varnish before assembly into piles for the part to be made. Unless they are insulated from each other, no good will be accomplished by using iron punchings instead of solid cast iron.

The iron punchings usually are made alike, on a special punch press on which a steel die is used to cut through the soft iron sheet metal fed into the press. Bolts or rivets generally are used to hold the punchings or laminations tightly together. The shellac or varnish on the laminations also helps to "glue" them firmly together. (Transformers on poles sometimes hum loudly because the iron laminations of the core have not been tightly clamped together, and therefore vibrate with the alternating flux.)

91. Problems of the Manufacturer. It is quite a difficult engineering task to correctly design and build a good generator for a definite job. Some of the more difficult problems involved are listed here, just to bring to your mind the fact that the engineer, the electrician, the draftsman, and the machinist all have to be "good" at their jobs to be able to build an efficient generator or motor.

PROBLEMS OF THE MANUFACTURER

1. Getting the right (best) kind of iron for the magnetic parts.
2. Making all punchings (laminations) exactly alike.
3. Winding perfect coils — no breaks, shorts, or grounds.
4. Perfectly insulating all windings from the frame.
5. Making a good commutator assembly.
6. Making good brushes and brush assembly.
7. Designing the machine so it will not overheat on load.
8. Making good bearings for long, steady service.

Behind the excellent, low-priced machines on the market at present stand long lines of trained workmen, who do their little bit in the vast manufacturing processes that must come first, before their products can be finally assembled into the generator or motor. Always see behind the finished product — see the hundreds and thousands of men and women whose craft, skill, labor, intelligence, and patience must be counted as part of the product just as much as the iron, copper, cotton, or rubber.

Without the active co-operation of this vast army, including miners and engineers, skilled and unskilled labor, the finished product would hardly be possible. This is a worth-while viewpoint for everybody to have.

SUMMARY

All generators produce alternating current inside their armatures.

Kinds of generators:

1. A.C. — all have "slip rings" and brushes.
2. D.C. — all have commutators and brushes.
   a) Shunt generators — field in parallel with armature.
   b) Compound generators — have two sets of fields:
      (1) Shunt fields, in parallel with the armature.
      (2) Series fields, in series with the load.

The commutator is merely an automatic switch, to change the generated a.c. in the armature to the desired d.c. for the line.

Terminal voltage is always less than generated voltage.

$$E_T = E_G - I_A R_A, \text{ where } E_T = \text{terminal voltage.}$$
$$E_G = \text{generated voltage.}$$
$$I_A R_A = \text{armature "drop."}$$

Shunt generators, under increasing load, have a lower E_T.

Compound generators, under increasing load, have a steady E_T.

Generated voltage depends on speed, flux, and turns on the armature.

1. Speed increase produces greater voltage.
2. Flux increase produces greater voltage.
3. Series-connected armature turns produce greatest voltage.
4. Parallel-connected armature turns produce greatest current.

Laminations are thin varnished iron punchings. Laminating the iron poles and armature prevents eddy currents.

Eddy Current is generated in the iron, instead of where it belongs in the copper wires. Eddy current is wasted energy that causes a machine to overheat.

Rheostats, in the field circuits, are used to control the generator output:

1. Shunt-Field Rheostat in series with shunt windings.
2. Series-Field Rheostat in parallel with series winding.

Operating Rules for generators:

1. Paralleled generators must be the same type and voltage.
2. Always start with no load on the machine.
3. Adjust rheostats to correct the terminal voltage to the desired value.
4. Never overload or short circuit any generator.
5. Cut off the load before slowing down the generator.

PROBLEMS

Prob. 1. A wire must cut through 100,000,000 lines of flux per second to generate 1 volt. Calculate the voltage generated in a wire that steadily cuts 50,000,000 lines of flux in 4 seconds.

Prob. 2. Find the generated voltage in a wire that "cuts" 5,000,000 lines of flux in 1/10 second; in 1/25 second.

Prob. 3. How many lines of flux must be cut by a wire in ¼ second to generate .5 volts? To generate 2 volts?

Prob. 4. By cutting down the flux on a generator to 1/3 the original amount, what will the new voltage be? Why?

Prob. 5. Diagram a scheme similar to Figure 67, having **two** poles instead of only one magnet, as shown. Show the connections.

Prob. 6. If each turn on a generator armature produces .25 volts, find the turns needed to deliver 150 volts total.

Prob. 7. What connections must be used in Problem 6? Why? Explain.

Prob. 8. Show, by a diagram of a 2-pole generator, just how an alternating current is produced as the armature rotates.

Prob. 9. How does the commutator operate to change Problem 8 generated a.c. to d.c.? Use curves to explain.

Prob. 10. Draw a generator cross section. Label the parts and show by colors or sectioning lines the kinds of metals used in the various parts.

Prob. 11. Find the "drop" in an armature delivering 56 amperes, when the armature resistance is .25 ohms.

Prob. 12. If the "armature drop" in a generator is found to be 6 volts, when the armature current is 40 amperes, find the resistance of the armature.

Prob. 13. Find the resistance of a field coil that takes 1.5 amperes on a 100-volt circuit.

Prob. 14. Find the resistance of the armature of Problem 12 and the field of Problem 13, when connected in parallel.

Prob. 15. Find the total resistance of four 85-ohm field coils, connected in two-series groups of 2 parallel coils each.

Prob. 16. The *IR* drop in an armature is 3.5 volts. Find the armature current, if the armature resistance is .21 ohms.

Prob. 17. Diagram a 2-pole shunt-connected generator. Find the armature turns needed, if each turn generates .3 volts, and the total voltage desired is 250 volts.

Prob. 18. Find the voltage drop in the series field of a compound generator that has .06 ohms. The load (drawn through the series field) is 84 amperes.

Prob. 19. Find the voltage drop of an armature delivering 6.5 amperes. The armature winding consists of 2 paralleled wires, each No. 18 copper, 250 ft. long.

Prob. 20. Figure Problem 19, if the armature is rewound with No. 16 wire, the same lengths as before.

Prob. 21. Find the length of No. 18 copper wire to be wound in a field coil so it will draw only 5 amperes on a 75-volt d.c. line.

Prob. 22. Find the voltage drop in a series-field winding of .025 ohms when the load current through it is 8.5 amperes.

Prob. 23. Find the "drop" in the brushes-commutator contacts of a generator delivering 65 amperes from its armature, when the brush-contact resistance is .034 ohms for each of the two brushes.

Prob. 24. What advantage has a compound generator over a shunt generator? Explain how this advantage is gained.

Prob. 25. Why is constant voltage an advantage on a city power and light system?

Prob. 26. Find the resistance of the armature of a shunt generator if the generated voltage is 124 volts and its terminal voltage is 119, while the armature current is 50 amperes.

Prob. 27. A shunt generator produces 125 volts. The armature resistance is .2 ohm. Find the terminal voltage when the armature current is 35 amperes.

Prob. 28. How can the polarity of a generator be reversed without reversing the armature? Explain with diagrams.

Prob. 29. A shunt generator has 120 volts, generated; the armature resistance is .3 ohm. The machine is supplying 15 amperes to the load and 1 ampere to the shunt-field circuit. Find the armature current.

Prob. 30. Find the voltage drop in the armature of Problem 29 generator.

Prob. 31. Find the terminal voltage of Problem 29 generator.

Prob. 32. Find the resistance of the shunt-field circuit, and the load in Problem 29 circuit.

Prob. 33. Diagram a compound generator where the armature resistance is .3 ohm; shunt-field current is 1.5 amperes; series-field resistance is .01 ohm; load current is 20 amperes; armature generated voltage is 120. Find the armature current.

Prob. 34. Find the "armature drop" and armature terminal voltage in Problem 33 generator.

Prob. 35. Find the series-field drop in Problem 33 generator.

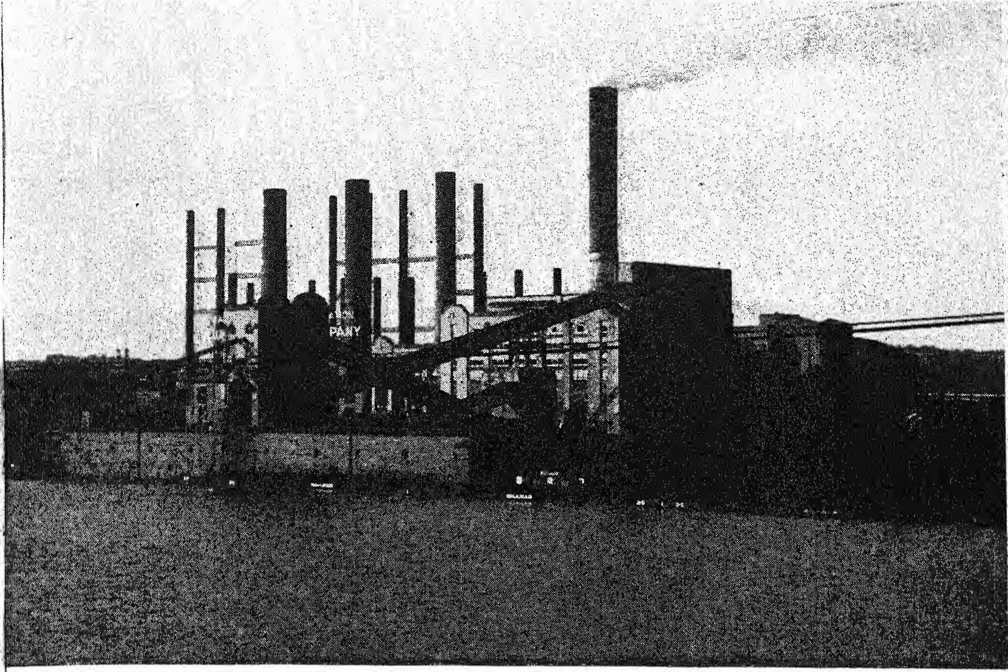
Prob. 36. Find the resistance of the shunt-field winding in Problem 33.

Prob. 37. Find the voltage at the load and the resistance of the load in Problem 33 circuit.

Prob. 38. Find the number of parallel shunt generators needed to deliver 500 amperes, if each unit can safely supply up to 210 amperes. Diagram the circuit.

Prob. 39. What voltage is actually being generated in a shunt machine if a voltmeter across the main terminals reads 116 volts, when the armature is delivering 45 amperes, the armature resistance being .1 ohm?

Prob. 40. Explain why the development of large power generators has revolutionized the modern industrial age.



FROM COAL TO ELECTRICITY

Huge steam boilers transform the heat energy of the coal into mechanical energy, latent in the steam. Turbines use this steam to drive great alternators, to feed the transmission lines of a metropolitan area of steel mills, manufacturing, and business. Pulverizing the coal before burning it reduces smoke and ashes to a minimum.

This power plant can generate 500,000 k.w., transmitted at 66,000 and 22,000 volts to ring circuits supplying stepdown stations.

The coal arrives via rail and river. Coal-handling facilities are designed to amply care for fuel.

Chapter VI

DIRECT-CURRENT MOTORS: ELECTRONS WORKING

IF THERE were no uses for electricity, as in motors in street cars, in rolling mills, and in home equipment, all our large generating equipment and distribution systems would be unnecessary. But, perhaps, since motors are so extensively used, d.c. motors should have been discussed before d.c. generators. The two, however, are so very similar that it does not make much difference which comes first.

The section assemblies of a 4-pole d.c. machine, made in Experiment 32, will equally well represent the d.c. motors to be discussed here. And the paper schematic model of a 2-pole d.c. machine, made in Experiment 33, also will be a very useful "tool" for studying the action of a d.c. motor. So keep these things handy.

The kinds of d.c. motors are similar to the kinds of d.c. generators (see Art. 85). They are:

1. **Shunt** motor — with a parallel-field supply;
2. **Series** motor — with a series-field supply; and
3. **Compound** motor — with both shunt and series fields.

More will be said about these particular types of d.c. motors later.

93. Why a Motor Runs. To learn the reasons why a motor runs, review Experiments 3 and 4. Remember that motors are, after all, just several electromagnets arranged so that like poles can repel, and unlike poles can attract each other. No matter how complicated a motor may appear, these two simple laws of magnetic fields are the only explanation of why it runs. This simplifies the theory of motors so that it is easy to experiment with, and just as easy to understand.

Experiment 35. The principle of an electric motor. Materials needed: a No. 6 dry cell; the special double-pole electromagnet

made in Experiment 26; some insulated copper wire, about No. 26.

Set up the electromagnets as shown in Figure 86, so that the current to them also must pass through the long loop of wire X–Y. Do not connect the end of the circuit, Z, until all other details of the experiment are in order and ready for observation.

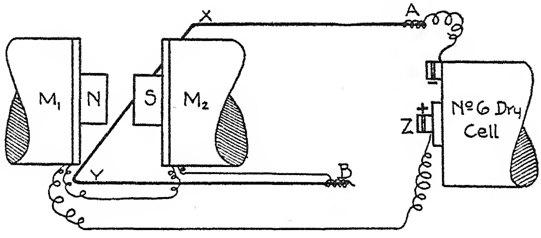


FIG. 86. The principle of an electric motor.

Hold loop X–Y so that it is fairly free to move through the magnetic-pole gap, between M_1 and M_2. Have the magnets so connected in series that one is N and the other is S, to get a very strong flux in the gap. When the loop X–Y is at rest in the center of the gap, touch Z to the battery terminal. Notice what the wire X–Y tries to do. Which way does it move? Why does it move? (Be careful not to cause the movement by any wiggle of the A connection.)

Repeat the experiment, but first reverse the dry cell, so a complete reversal of current and flux will occur. Will this reverse the motion of the wire? Try it. Were you right? How does the wire X–Y move now?

Arrange to reverse the current in X–Y **only.** Keep the same magnet polarity as before. Do this by reversing the leads at A and B. Then touch the Z connection to the battery post. Which way does the X–Y section of the loop move now? Why? What condition seems necessary to reverse the motion of the wire? Why doesn't it reverse when **both** magnetic flux and wire current (in X–Y) are reversed?

Try out other magnetic-pole connections in this experiment. Keep a record of your connections, in sketches similar to Figure

86. On each sketch show current direction, flux direction, and wire motion, in that case.

Notice that a **Left-Hand Rule for motors** may be used in these cases; this rule is similar to the Right-Hand Rule for generators, in the manner of use. This rule states that when the thumb, first finger, and center finger of the left hand are held at right angles to each other, as in Figure 87, then the

Thumb points in direction of motion of the wire;

Forefinger points in direction of flux lines from the poles;

Center finger points in direction of current in the wire.

Compare this rule to that given in Article 69 for generators. Notice that they are exactly alike, **except for the hand used.** This simply means that, for a generator to operate as a motor, or for a motor to operate as a generator, only **one** of the three — motion, flux, or current in the wire — need be changed.

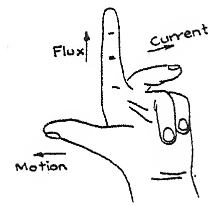


FIG. 87. The Left-Hand Rule for motors.

The drawings in Figure 88 show why this rule is true for motors. These views refer to an arrangement as in Experiment 35, Figure 86, where a wire carries current through a very dense magnetic field, which causes the wire to be thrust out of the field. The direction of this motion depends upon the direction of the flux in the gap and the current flow in the wire. In *a*, Figure 88, only the flux of the poles is shown. Part *b* shows the flux around the wire (X–Y as in Experiment 35) as it carries current from X toward Y, or out of the page.

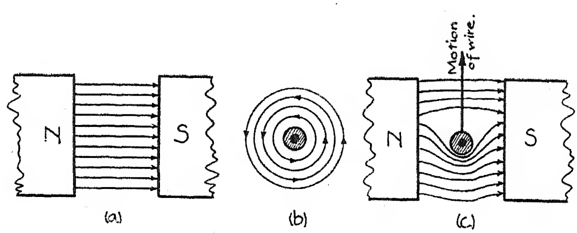


FIG. 88. (*a*) Field of magnets alone; (*b*) field around wire carrying current; (*c*) the two fields combined.

Part *c* shows the combined effect of these two flux sources, when the wire carries current between the magnetic poles. The flux on top of the wire is lessened, and the flux lines beneath the wire are strengthened. If these flux lines were elastic, like rubber bands, how would they force the conductor to move? The wire would be moved up, of course. Check this carefully with the Left-Hand Rule for motors.

94. Experimental Motors. Some very interesting experimental or model motors can be quite easily made from ordinary workbench "odds and ends." Some of these models are more of a toy than a practical type, but nevertheless are interesting.

Experiment 36. Moving a wire electrically. Materials needed: a No. 6 dry cell; a strong electromagnet, or materials from which to make it; some sheet metal cut from a tin can; a wooden base.

This experiment is just a refinement of the method used in Experiment 35, to show how a wire carrying current through a strong magnetic field will be made to move by that flux.

The electromagnet may be mounted on a tin bracket, as shown in Figure 89. The middle of its pole face should be about 1 inch above the baseboard. This magnet will act as the field of the motor.

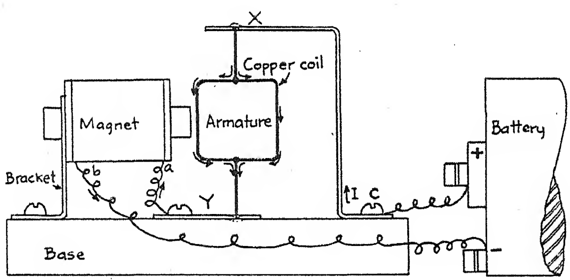


FIG. 89. An elementary electric motor.

The "armature" of the model now may be made. First, arrange a top bearing, *X*, and a lower bearing, *Y*, made of sheet tin. Fasten these on the baseboard, about as shown in Figure 89. Make sockets in the bearing plates *X* and *Y*, for the ends of the armature. These "dents" can be made with a blunt nail and

hammer, nearly punching through the tin plates. Do not make holes in the plates, because holes will only bind the armature. The "armature" proper is a loop of copper wire, with two copper shafts which also act as current leads to the loop. These ends or shafts must be smooth and round, to fit neatly into the dents in the plates *X* and *Y*. Make the shafts just long enough to fit snugly into their two bearing sockets. Bend the upper bracket, *X*, to get the best adjustment.

Connect one magnet lead to the plate *Y*. Make the other two connections, as shown, to the dry cell. The loop may have to be spun to start it, but it should keep running under battery power alone. Of course, such a model has little power, as we commonly speak of power in units of horsepower. This model probably would be about "one mosquito power." But the model does show just how and why a larger motor runs.

This model is a **series motor**, meaning that the armature and field windings are in a series connection. Such motors as used on electric trains and street cars are **series motors**.

Try reversing the armature current, without reversing the field current. Connect lead *a* to screw *c*, and then connect plate *Y* directly to the battery + side. Does this new connection reverse the motor? It should. Why?

Explain the motor direction in your model by the **Left-Hand Rule** for motors. What part of the total current coming to the armature loop in bracket *X* is actually used to make the loop turn? (Half. Why? Where is the other half of the current in the loop?) A real series machine has at least two magnetic poles, so that this other half of the armature current also can be used to make the armature turn.

Would iron, inside of the armature loop, help any? Why? Why should this iron be laminated?

Experiment 37. Using a generator as a motor. Materials needed: a No. 6 dry cell; the model generator made in Experiment 30; some insulated connection wire.

Motors and generators are similar in all details, except that motors convert electrical energy into mechanical energy, while generators convert mechanical energy into electrical energy.

Remove the rubber-band "drive belt" from the model generator. Make sure the armature can turn easily. The brushes

must touch the armature wires but not too hard to stop the armature.

Connect the field and armature (brush connections) in series as a series motor. Now connect the machine to your dry cell. The armature will turn under the battery power, if given a slight start in the right direction. Use the Left-Hand Rule to determine which direction is correct for the armature to rotate.

The wiring diagram for this series-connected motor is shown in Figure 90 in simplified form. Notice that whatever the current is through the armature of this series-type motor, the same current also flows through the field circuit. The series field is always labeled "SE."

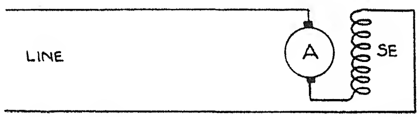


FIG. 90. Simplified diagram of a series motor.

Experiment 38. Making a simple 2-pole series motor. Materials needed: a No. 6 dry cell to run the motor; about 12 ft. of insulated wire (No. 26 will do); some heavy sheet iron (a tin can); 6 screws, for a neat job, as shown; wood for a baseboard, as shown.

First, study the motor details, as shown in Figure 91. This is a full-size sketch, and, therefore, may be used as a "template" for the parts to be made.

Cut from the tin can (soft iron) or sheet iron, 6 strips about 6 in. long and ⅜ in. wide. The edges should be straight and smooth. Use a file or emery cloth to smooth them.

Form these strips into the pieces needed for the field, the armature, and the bearings, as shown. Bend the iron strips with pliers, and make them exactly the shape shown in Figure 91. This will be easy, because Figure 91 is a full-size sketch of the motor, and you can lay your metal strips edgewise on the drawing to see that they are the correct shape. The pieces needed are:

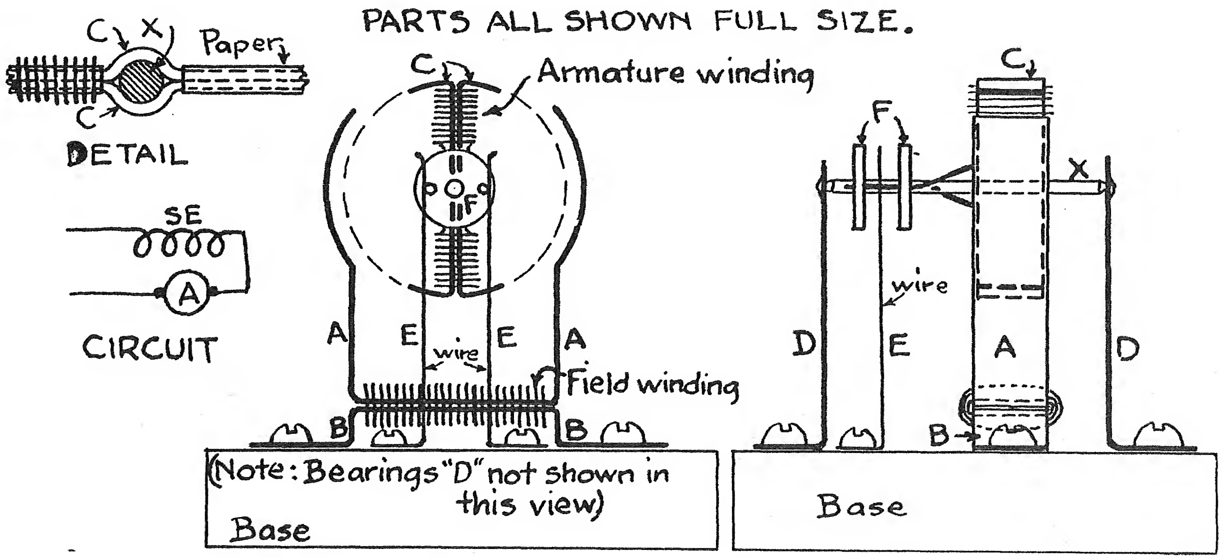


FIG. 91. A simple series motor.

		Pieces	No. Required
Field	motor poles and field base	A	1
		B	1
Armature	armature poles	C	2
Bearings	for armature	D	2

When these 6 pieces are properly bent to shape, make holes in pieces *B* and *D* for the screws to fasten through into the baseboard.

Then make deep dents in pieces *D* (bearings), to take the pointed ends of the armature shaft *X*. Be careful not to punch through the metal. This method of making bearings for small motor models is better than making holes for the shaft.

Bind parts *A* and *B* tightly together with a strip of heavy wrapping paper, about 1⅛ in. wide by 3 in. long. Do the same with the two armature parts, *C* and *C*. Be sure you leave room for the shaft, as shown in detail in Figure 91. The strips *C* should be formed to tightly clamp on the shaft *X*. Now the field and armature are ready to be wound with the insulated copper wire.

Cut the head off a nail. Sharpen the ends with a file to make the shaft X, which should be about 1½ in. long. Insert this in the armature assembly just made, so the shaft and armature are placed as shown in Figure 91.

Wind the field first. This winding should be about three layers of wire in the coil as shown in Figure 91. Leave 3- or 4-in. leads on the winding for connections.

Next, wind the armature coils, with an equal number of turns on each side of the shaft *X*. **Note: All turns of this winding must be in the same direction, around the iron forms *C–C*. Begin this winding at the middle of the armature, and end up also at the middle.** This will bring out both ends of the armature winding at the shaft, for easier connection to the commutator. Two complete layers of turns on the armature will be enough.

The commutator on this model is made very simply, to "cut in" the armature coils at the right instant to the correct side of the line. The commutator on this motor is made of two card-

board disks, about ½ in. in diameter, punched to fit tightly on the shaft *X*. The two ends of the armature winding are cut short and scraped bare, and are pushed through small pinholes in these *F* disks, as shown in Figure 91. The wire between the disks acts as the two bars of a commutator, similar to those shown in Figure 72, for a d.c. generator (or a d.c. motor).

Mount the field and bearings as shown. Adjust the bearings *D–D,* so that the armature-shaft points fit nicely in the bearing "dents."

Make two "brushes" of bare copper wire, and fasten them on the baseboard. The brushes must touch the "commutator" bars when the armature is in a vertical position, as shown. Otherwise, the motor will **not** work. Be careful of this detail; it is very important.

Connect the machine as a **series** motor — so the armature and field windings are in series as in Figure 90. One dry cell will operate your model. Slight adjustment of the brushes will improve the operation of the motor.

To reverse this motor, the field **or** the armature flux must be reversed, but not **both.** Try this out on the model. Can you fix up a switch that will reverse the motor? Try it. You will probably have to use a double-pole, double-throw switch to do the job.

95. The Purpose of the Commutator and Brushes. The commutator on a d.c. motor is exactly like that on a d.c. generator. In either case, the commutator consists of a series of copper bars insulated from each other and from the armature shaft. Their purpose is to provide a means of making a connection with the armature coils, even though they are revolving, and, at the same time, to reverse the direction of the current at the proper instant.

The purpose of the brushes is to provide a means of getting the current into or out of the armature, through the commutator bars. These brushes usually are made of a special kind of carbon, which lubricates itself and does not wear the commutator bars as would a copper brush. Yet, the carbon makes a fairly good contact with the bars. Springs are used to hold these brushes firmly against the commutator. Examine your 4-pole d.c. machine sections to see how the brushes are held in place and are adjusted (see Figs. 74 and 75).

Experiment 39. Making small commutators (general idea). Many times the model motor made would operate much better if a good commutator were put on it. Here is a simple method of making a small, neat commutator for model motors.

First, wrap the armature shaft with a long, narrow (¾ inch) strip of heavy brown paper, glued its entire length. Let the glue (or mucilage) become almost dry before applying the strip to the metal shaft. Be sure the shaft is clean, and rough enough to grip the glued paper. Allow this built-up paper "tube" to become thoroughly dry.

Now, cut a strip of thin brass or copper so it is a little narrower than the paper strip was — say about ⅝ in. wide. Clean the strip bright, with emery cloth. Bend the copper strip around the paper tube, and cut it so it just meets around the paper tube.

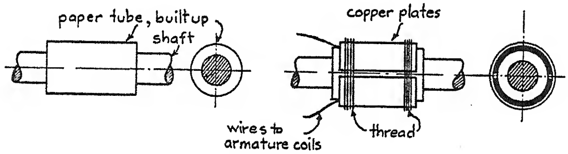


FIG. 92. Details of a small commutator.

Cut this strip into the number of commutator "bars" required (usually two on a small 2-pole model), and then cut off about 1/16 in. more from each "bar." This will leave about 1/16 in. between the bars when assembled.

Glue these pieces (bars) onto the paper insulator tube on the shaft. Hold the copper bars in place with several turns of thread on each end, as shown in Figure 92. This thread can be left on permanently. But do not have any thread at the middle of the bars where the brushes must bear.

The armature wires may be fastened to the commutator bars by soldering, or by pushing between the bars and the paper. Be sure to have the commutator assembled on the shaft in the right position of the bars. The breaks between the bars must pass under the brushes of the machine just as the armature poles get past the center of the field poles. Otherwise the motor will not operate.

96. Construction of an Ammeter. Meters of any kind are simply motors, kept from turning completely around by springs that hold back the armature. Sometimes these same springs also are used to bring current to the moving armature coil.

There are two main types of ammeters: the **moving-vane** type, in which an iron vane is pulled into a coil or toward an electromagnet; and the **moving-coil** type, where a coil is mounted so it can turn, as an armature does, between magnets.

Cheap, sturdy ammeters, such as are used on automobiles or around stores, are usually of the **moving-vane** type. This type is easily made, and is much cheaper than the **moving-coil** type. The **vane** type can also stand "worse treatment," and survive, than can the **coil** type. But, the **coil** type is much more accurate than the **vane** type.

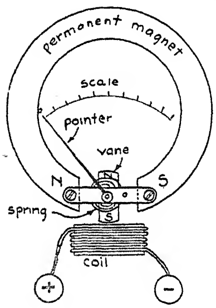


FIG. 93. The moving-vane ammeter.

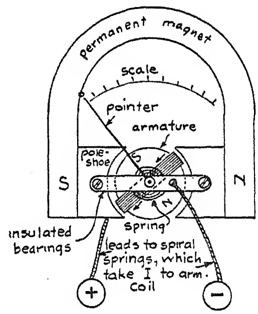


FIG. 94. The moving-coil ammeter.

In the vane-type instrument shown in Figure 93, the coil carries the current to be measured (amperes). This current causes a flux, which distorts the flux in the gap, angling it around a little. The vane, also being magnetized, adjusts to the new flux, thus moving the pointer over the scale.

In the coil-type instrument (Fig. 94), the same effect is accomplished by mounting the coil right as a moving armature. When this coil carries current, it will have *N–S* poles, as shown. The rule for magnetic fields (like poles, etc.) gives the reason why the coil turns in the permanent-magnet flux. In turning, the coil moves the meter pointer over the scale.

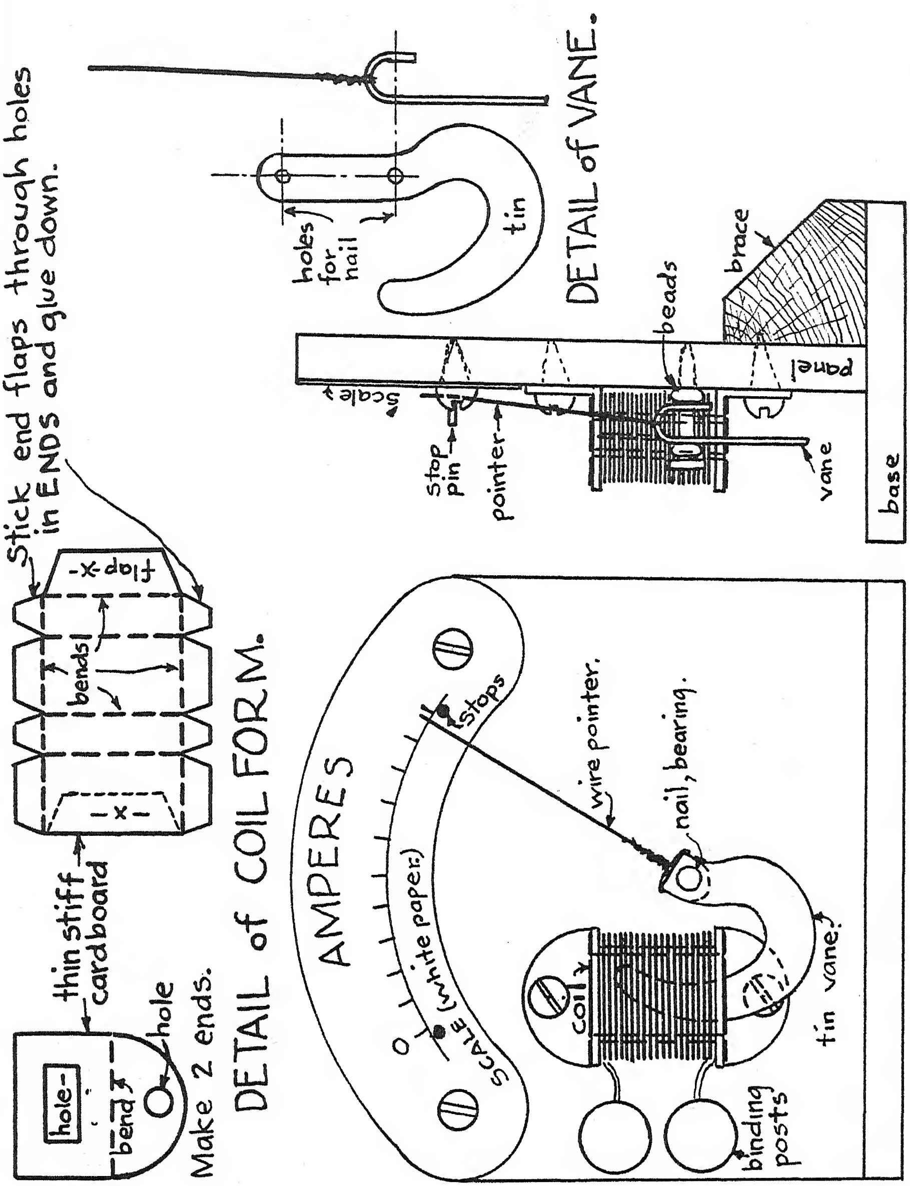


FIG. 95. Details of a simple d.c. ammeter.

Experiment 40. Making an ammeter. Materials needed: a small piece of heavy tin (soft iron); cardboard; white paper for the scale; two binding posts of some kind; heavy insulated wire (doorbell wire) for the current coil; wood for the meter base.

Cut, out of the tin, a piece exactly the size and shape shown in the detail in Figure 95. This will be the moving vane of the meter. Make small holes in the vane, as shown, for the small nail or pin which is to serve as a bearing shaft for the vane.

Bend the vane to shape, as shown. Fasten a very thin wire pointer (copper wire, No. 30, will do) to the vane.

Now cut, out of the cardboard, the tube and two end pieces needed to make the coil form. This form must have a hole in it ¼ by ½ in., as shown. Glue the tube together, and then glue the ends on the tube, with the tube flaps on the outside of the ends.

Cut, out of a wood stick, a filler for this coil form, to hold it securely during the winding of the heavy wire. Without this wood filler, the heavy wire will crush the cardboard tube in the winding process. The long stick will also serve as a handle during winding.

Wind 6 turns of No. 18 insulated wire on the form, tightly, with neat, square, coil corners. Leave about 3-in. leads on the coil for connections. The coil may be covered with a cardboard strip for a neater job.

Make a wood base and upright panel for the parts, as shown in Figure 95. A small block behind the panel will do much to strengthen the meter board. Curve the top of the panel to make a neat job.

Mount the current coil, the vane-needle movement, and the binding posts as shown. Connect the coil leads to the binding posts. Arrange a white paper scale at the top of the panel, as shown, but do not mark the scale on it.

All meters have to be "calibrated" — their scales have to be put on after comparison to a meter already known to be correct (a "standard" meter).

To Calibrate the Meter: Connect this ammeter in series with an ammeter already known to be fairly accurate, with a scale from 0 to about 35 or 40 amperes. In this series connection, send current from a dry cell through the meters. The current will be the same in both meters. The 0 point (zero) will,

of course, be where the needle rests at **no current**. This point and two or three other points on the scale will allow you to complete the scale by filling in as shown.

Note that this homemade ammeter must be used with the meter panel in a **vertical** (upright) position. In this position, gravity supplies the same effect as the coil springs do in commercial-meter models.

97. The Construction of a Voltmeter. Voltmeters are similar to ammeters. The only great difference between the two is in the kind of coil windings. Ammeters have a few turns of large wire on the coil; voltmeters have many turns of fine wire on the coil. Otherwise, their details and types are quite alike. The views in Figures 93 and 94 also would serve to show how "vane-type" and "coil-type" voltmeters look.

See Table XI (page 68) for the resistance of ammeters in general compared to that of voltmeters in general. Because the voltmeter is connected **across** the line it is to measure, its resistance must be very high to cut down its current to a very small amount.

Experiment 41. Making a voltmeter. Materials needed: same as used for the ammeter (Experiment 40) except that the coil will be wound with very fine wire instead of heavy wire. The enameled wire from an old spark coil will do for this.

Make this meter in the same way as the ammeter described in Experiment 40, but wind the cardboard coil form with about 250 to 300 turns of very fine wire. This wire should be about No. 36 or 40, enameled. The ends of the coil winding are brought out to two binding posts, as in the ammeter model.

To Calibrate the Meter: Connect this voltmeter in **parallel** with a voltmeter whose readings are known to be accurate. These readings will thus be equal. Whatever the "standard" voltmeter reads on a battery source, the model voltmeter also must read. When three or four points are found on the model's scale, the other points may be filled in quite accurately enough for all practical uses of the model. This meter cannot be used to measure an **alternating** current.

Note that this voltmeter model, as in the case of the ammeter model, must be used in a **vertical** position of the meter panel. The voltage coil operates the vane against the force of gravity on the vane. By making the meter thus, no spiral springs

need be used, as in commercial models. This would not be generally practical, but is permissible in such a homemade model that can be more carefully used than most meters are.

98. Motors and Generators Are Similar. All the construction details of a d.c. motor are exactly like those of a similar type d.c. generator. Table XV and Figure 73, in Chapter V on d.c. generators, are also applicable to a 4-pole d.c. motor. Table XVI and Figures 74 and 75 are equally true when meant for a standard 4-pole d.c. motor.

Therefore, you already knew all about d.c. motors as soon as you had learned about d.c. generators. The paper model you made in Experiment 33 will do very nicely to show the details of flux and windings in a 2-pole d.c. motor. Notice that, in this model, as you **face the brushes**, the armature will travel **counterclockwise**, as a d.c. motor.

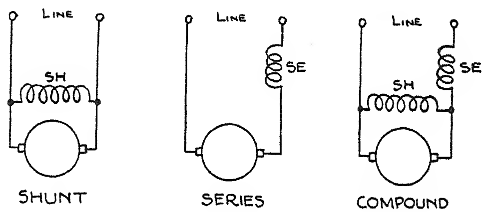


FIG. 96. Simplified diagrams of d.c. motors.

99. Types and Uses of D.C. Motors. D.C. motors, being similar to d.c. generators, are built in similar types. Refer to Article 85 for a comparison with the following data. (NOTE: series generators are not commonly used, and so were omitted in Article 85.)

Types of D.C. Motors:

1. **Shunt** motors — fields in **parallel** with the armature.
2. **Series** motors — fields in **series** with the armature.
3. **Compound** motors — with **both shunt and series** fields.

The diagrams in Figure 96 show the (simplified) connections of these three main types of d.c. motors. Examine them; compare them with the diagrams for similar types of d.c. generators.

Shunt motors are used on jobs where the speed must remain fairly constant, regardless of the power being used. The shunt motor, therefore, comes in handy in such places as machine shops.

Series motors have a peculiarity; their starting power is very great, much greater than the starting power of a shunt motor. So, wherever the work to be done is very hard to get started, series motors generally are used. Some of the commoner uses of this type of motor are: street cars, electric automobiles, and electric cranes. But series motors must always be connected with gears to their load, because they will "race" if a belt drive should break and release them from duty on the load. This speeding up would tear the armature apart and ruin the motor.

Compound motors, of course, combine the good qualities of both the shunt and series types. A compound motor runs at an even speed, and yet has a great starting power. This motor is useful on such jobs as rolling-mill work.

There is no doubt about the fact that electric motors have revolutionized the modern world. In modern electric ocean liners, skyscrapers, rolling mills, and the hundreds of other uses, motors have greatly lessened man's burden. In the near future, the streamlined electric train will be competing with the steam train for transcontinental schedules. Even on the farm the electric motor is rapidly taking over such labors as milking, threshing, grinding, pumping, washing, and many other duties. As a matter of fact, it is hard to find a part of the civilized world where the electric motor has not been put to work to do jobs that promote human welfare and ease, and hasten further progress. Small electric motors did much to make over the steel and iron mills and the wire industries. These industries in turn gave us larger and better motors and generators. Following out this line of thought would lead to many very interesting facts about home conditions, working conditions, employment, and the boy's need of an education these days more than ever before. Think it over — "What are the Outcomes of Superelectrification?"

100. A Motor Supplies Part of Its Own Power. Everybody knows that a machine is harder to start than to keep moving once started. Electric motors are no different, in this respect, than other machines.

Any motor takes more current to start than when it is up to normal running speed. This is shown graphically by the curve in Figure 97. When the main switch is closed, the armature at first is at rest. To start the armature turning, a great deal more line current is necessary than to keep it turning.

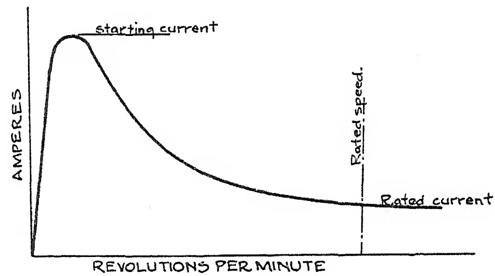


FIG. 97. Current in a d.c. motor compared to speed.

This heavy starting current often is ten times as much as the normal running current for the motor. That is the reason the house lights momentarily dim when the electric refrigerator motor starts to run.

Part of that "hump" in the curve can be properly blamed on the inertia of the motor "wanting to stay as it was before." But another reason can be found for the great drop in current, once the armature gets up to speed. To get at this reason, just imagine a motor armature turning in the pole flux. (Use your paper model to help you do this.)

The armature wires are cutting the lines of flux of the field poles, aren't they? Will this action cause a current to be generated in the armature? (Yes!) Why?

This generated voltage (counter e.m.f., it is commonly called) is always in an opposite direction to the voltage from the line coming into the armature. The generated voltage (counter e.m.f.) in a motor often comes up to as high as 90 per cent of the line voltage. This leaves only 10 per cent of the total energy used to be drawn from the line.

Even when the main-line switch has been opened, it is unsafe to touch the terminals of a big motor if the armature is still

turning. For, as long as the armature is moving at any considerable speed, the machine will have a generated voltage, or, as it is here called, a counter e.m.f. The prefix "counter" always means "reverse" or "opposite." So counter e.m.f. means a "reverse voltage," caused in a d.c. motor by the wires of the armature cutting through the field flux, which generates a voltage in them.

In fact, the whole idea here can be put down thus: $E_G = E_T - I_A R_A$, meaning that the counter e.m.f. (E_G) equals the terminal voltage (E_T) minus the armature drop. Note that in a motor the E_T is always greater than its E_G.

101. Care of a Motor. Because motors and generators are similar machines, their care and rules for general operation are also similar. Refer to Article 88 for the rules for the care of a generator. Compare them to these rules for the care of a motor:

1. Never overload the motor.
2. Never run a motor so hard or so long that it overheats.
3. Never oil the commutator or the brushes.
4. Keep the motor clean of "fuzz," dirt, and oil.
5. Keep the bearings properly oiled or greased.
6. Operate the motor only on the correct line voltage.

102. Protecting a Motor from Overloads. A motor, no matter what kind or size, should in some way be protected against all overloads. Perhaps you have been on a street car when the "circuit breaker" up over the motorman's head, in the cab, "blew out" with a loud bang and a spurt of fire. Or you may have seen a street-car fuse (on the car roof usually) being replaced after it has "blown out" on an overload. These were at least two attempts to protect the motors involved in each case against damage from overload. A motor is a costly piece of equipment, and should be protected, whenever possible, against all damage. A fuse costs less than a new motor.

Refer to Figure 34 for the schematic diagram of a circuit breaker. This kind of device is used, for example, on washing machines, to protect the driving motor from burning out in case the machine jambs up somewhere. The breaker "flies out" on too heavy a current, which will be drawn by the motor when it is doing too much work. This breaks the circuit of the main line to the motor, and thus saves the motor from damage.

A common fuse would also protect the motor, but, in the long run, would cost more than the small breaker, which can be "reset" after it flies out. On large motors, very sensitive "overload breakers" are always used, as a matter of good safety practice. It is well worth the cost of a circuit breaker to save the cost of a good motor any time!

103. Starting Boxes. The big "hump" in the curve shown in Figure 97 sometimes is too great for the motor to safely carry. In such a case, a big motor must be started at a **lower** current than usual, to save the line from overload.

No doubt you have noticed how the motorman on a street car uses the "controller" to get his car under way without too severe a start. And you have seen the neighborhood shoemaker slowly "cut in" his motor that drives the long line of rotary cutters, brushes, and sanders he uses. Without proper starting devices, the average large motor would not last very long.

The average **starting box** has two main parts: (1) a rheostat in the **armature circuit** of the motor; (2) a circuit breaker to protect the whole motor.

The connection of a standard type of starting box to a **shunt** motor is shown in Figure 98.

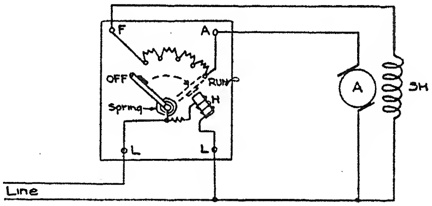


Fig. 98. A starting box connected to a shunt motor.

Notice the magnet coil labeled *H*. This coil is known as the holding coil, and acts as a circuit breaker, by releasing the switch-arm armature to OFF when the line current or voltage fails. A strong spring throws the switch blade to the *off* position when the *H* coil releases the armature.

The rheostat must be connected so that, as the switch arm is slowly brought over to the holding coil, the armature current will be slowly **increased** and the field current slowly **decreased.**

This condition will start the motor as soon as possible without damage to its coils. Too rapid a movement of the switch arm will offset these advantages of the starting box. Like any other piece of apparatus, a starting box must be used with "good sense," in order to get the most advantages from it.

No large or heavy-duty motor of any type, either a.c. or d.c., should be operated without an adequate starting box, correctly connected to the motor, and properly handled by the operator.

104. Automatic Controlling Apparatus. Riding in one of the newer types of automatic, high-speed, electric elevators always gives a thrill to the wide-awake passenger. The way the car gets up to speed, slows down to a stop at exactly the floor level, and how the doors open and close so softly and yet so securely, is all quite marvelous.

The secret of it all lies in automatic starting boxes, automatic stopping brakes, hundreds of relays (which are automatic switches), and the service of our faithful ally, the Electron. Many men have spent years at patient work in laboratories, men whose names never reached the "Front Page," but men whose genius and skill are all combined in the marvelous automatic devices so common to us. The relay, the automatic motor-control system, the automatic motor-driven switch, and many other similar devices have simply revolutionized modern living.

Whenever you have the opportunity to inspect the real "heart" of the elevator, for example — the automatic switch panel that is better than a human brain on the job — by all means do so. True, these automatic devices do take the place of some elevator boy or some telephone girl. But think of the greater number of highly skilled people needed to design and make these automatic machines. The future of automatic machinery points clearly to the release of mankind from the dangerous and ruinous labors that have been his so far. How does all this affect the economic order of things? of money? of leisure time?

105. Reversing a Motor. In your experiments with your model motors, you already have learned that, to reverse a d.c. motor, you must reverse either the field current, or the armature current — but not both. This is illustrated in Figure 99. Part (*a*) of this diagram shows that when both the field and armature fluxes are reversed, the poles are still being attracted and repelled the same way as before. Thus, reversing the line con-

nections to a motor does not reverse the motor armature direction. Then, how can a motor be reversed?

A way must be devised to reverse the connections to either the armature brushes or the field windings. This can best be done by using some kind of switch, which will reverse the current

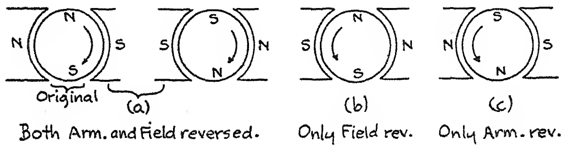


FIG. 99. Reversing a d.c. motor.

to the one winding but keep the other winding the same. Figure 100 shows what needs to be done to reverse a series motor, but the same procedure can be applied to shunt or to compound motors. (Note that, in a compound machine, it will be easier to reverse the armature, than to reverse both field windings. Remember that a compound machine has two fields — shunt and series.)

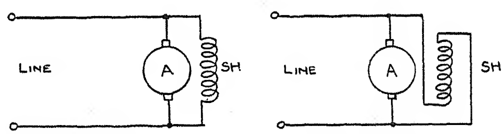


FIG. 100. Reversing a shunt motor.

Experiment 42. Making a reversing switch for a model motor. Materials needed: a wood baseboard; 6 small brass screws for contacts; some tin or copper strips for the two needed switch blades; connection wire.

Make two springy switch blades for the job, as shown in Figure 101. The best blades are made of copper, but tin-can strips will serve the purpose if no copper is available. Drill these two blades for the screws at X and Y. Make the blades exactly alike, with neat round ends.

Mount the wood piece W to the blades with small screws. The

blades must be loose enough to turn on the handle *W*, when it is operated in the completed switch unit.

Cut out a suitable wooden base for the switch. Smooth all the edges neatly. Mount on this baseboard the switch-arm assembly just made; the screws at *X* also must carry the wire "pigtails" or leads.

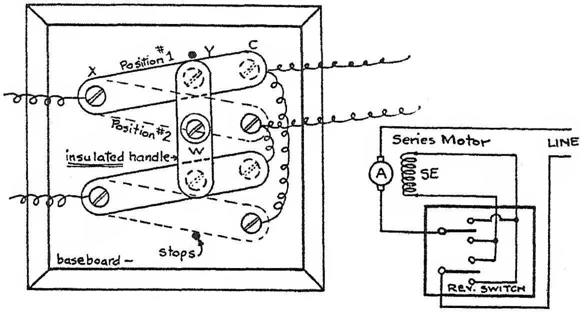


FIG. 101. A reversing switch for a model motor.

Now you can be sure just where to mount the contact screws *X*. Mark the places for these contact screws with a pencil, to be sure the blades will touch them properly when actually put in place. These screws also must hold down short leads.

The wiring diagram in Figure 101 shows how to use this switch to reverse a model series motor. Trace out the current path through the diagram when the blades are in position 1, and then when in position 2. Why does this switching reverse the motor?

How are street-car motors reversed? Where is the reversing switch located? Who operates it? When?

Figure out how to use your reversing switch to reverse a shunt motor. Note that the only idea involved is to reverse either the armature current or the field current, but not both. You can easily try out your shunt connection on your model motor made in Experiment 38.

SUMMARY

Kinds of d.c. motors — Shunt, with field in parallel with armature.

Series, with field in series with armature.

Compound, with both shunt and series field windings.

Why a motor runs — like poles repel; unlike poles attract.

Motor Rule — Left Hand: thumb and two fingers all at right angles.

Thumb in direction of motion of the wire.

Forefinger in direction of the flux from the poles.

Center finger in direction of the current in the wire.

Parts of a d.c. motor are similar to those of a d.c. generator:

Field poles supply the flux for the armature.

Armature holds the wires, and is turned by their turning.

Commutator is to reverse the armature current at the right instant, so the armature keeps on revolving.

Counter E.M.F. in a motor (E_G) is really the generated voltage.

$$E_G = E_T - I_A R_A;\ \text{or},\ E_T = E_G + I_A R_A.$$

Starting current is always greater than running current.

Starting boxes are used to cut down this starting current.

Reversing a motor: reverse either the field current or the armature current, but not both.

PROBLEMS

Prob. 1. A motor armature on a 2-pole machine has 2 parallel paths for current. Find the armature resistance if each path carries 6 amperes on a 150-volt line.

Prob. 2. Find the resistance of one armature coil made of 150 ft. of No. 18 copper wire.

Prob. 3. Rewinding this coil, using 250 ft. of No. 22 copper wire, will have what effect on its resistance?

Prob. 4. Calculate the resistance of a large field coil wound with 550 ft. of No. 16 copper wire.

Prob. 5. Find the voltage drop in this coil when carrying 7.5 amperes; at 10 amperes.

Prob. 6. A field coil is wound with 185 ft. of No. 26 copper wire. Find the current in this coil on a 110-volt line.

Prob. 7. Find the total resistance of a d.c. motor that draws 6.5 amperes on a 110-volt line. What current will be drawn by this machine on a 120-volt line?

Prob. 8. Diagram a small coil of wire hung in the pole gap of a large U-shaped magnet. Will this coil turn when a current is passed through it? Why?

Prob. 9. Will this coil keep on revolving? Explain.

Prob. 10. Does this coil in Problem 8 illustrate the motor principle? How? What is the purpose of the commutator on a motor?

Prob. 11. Why are coil springs used in commercial meter models? Does the spring strength affect the meter readings? Why?

Prob. 12. If an ammeter (resistance — .05 ohms) was connected across a 60-volt line, find the current. Is this dangerous?

Prob. 13. Find the current drawn by a 600-volt voltmeter (resistance — 750,000 ohms) on a 550-volt line. Is this a "wasteful" meter? Must a meter use current? Why?

Prob. 14. Find the resistance needed in the line to a 6-volt, 3-ampere shunt motor, to operate it on a 10-volt line. First diagram the circuit.

Prob. 15. Calculate the resistance needed in Problem 14 circuit to cut the motor current in half.

Prob. 16. A shunt-motor field has a resistance of 32 ohms. Find the field current of this machine, operating on a 50-volt line. Diagram.

Prob. 17. Find the resistance needed in series with Problem 16 field, to cut the field current down to 1 ampere. Diagram this change.

Prob. 18. How will Problem 17 change in the motor circuit affect the speed?

Prob. 19. Diagram a series motor on a 120-volt line. The motor draws 8 amperes at rated speed. The armature resistance is 3.5 ohms. Find the armature voltage drop under these conditions.

Prob. 20. Find the total resistance of Problem 19 motor. Find the series field resistance.

Prob. 21. Suppose a field coil is rewound with twice the original length of wire, this wire having only half the cross section of the old wire. How will this change affect the coil's resistance? Why?

Prob. 22. Find the resistor to use with a 32-volt motor (rated at 4 amperes) when the motor is operated on a 110-volt line.

Prob. 23. Suppose the counter e.m.f. in a 120-volt (terminal) shunt motor is 114 volts. Find the armature drop in this machine. Diagram.

Prob. 24. If the armature of Problem 23 motor has .8 ohms, find the normal running armature current.

Prob. 25. Find the field current of Problem 23 motor, if the field resistance is 100 ohms.

Prob. 26. Find the total line current to Problem 23 motor, when running.

Prob. 27. Suppose the starting current usually is about 9 times as great as the running current in a motor. Find the starting current for Problem 23 motor.

Prob. 28. Explain why the starting current in a motor is always greater than the running current. What is counter e.m.f.?

Prob. 29. As the speed of a motor increases, what happens to the counter e.m.f.? Why? How does all this affect the line current to the motor?

Prob. 30. If the running current of a small motor is known to be 4 amperes, find the fuse rating needed to protect this motor.

Prob. 31. Diagram fuses as protective devices for a shunt motor.

Prob. 32. Diagram a circuit breaker as protection for a shunt motor.

Prob. 33. Why must a series motor always be connected to its load by direct shaft or gears that cannot slip or break?

Prob. 34. Why is it impossible for a motor and a generator to run each other, as a perpetual-motion machine? Explain.

Prob. 35. If the permanent magnet of a meter weakens, how does this affect the meter readings? Explain.

Prob. 36. Diagram a starting box used with a series motor. The *"F"* terminal is **not** used in this case.

Prob. 37. Repeat Problem 36. Add the shunt-field circuit, properly connected to the "F" terminal, so that you now have a compound-motor circuit.

Prob. 38. Make a table of d.c. motor data; the table should have 4 columns: type name, diagram of the type, characteristics, and uses.

Prob. 39. Diagram the connections for a reversing switch used on a shunt motor. Check the circuits carefully. What causes the motor to reverse?

Prob. 40. Repeat Problem 39 for a compound motor. (Reverse the armature current here.)

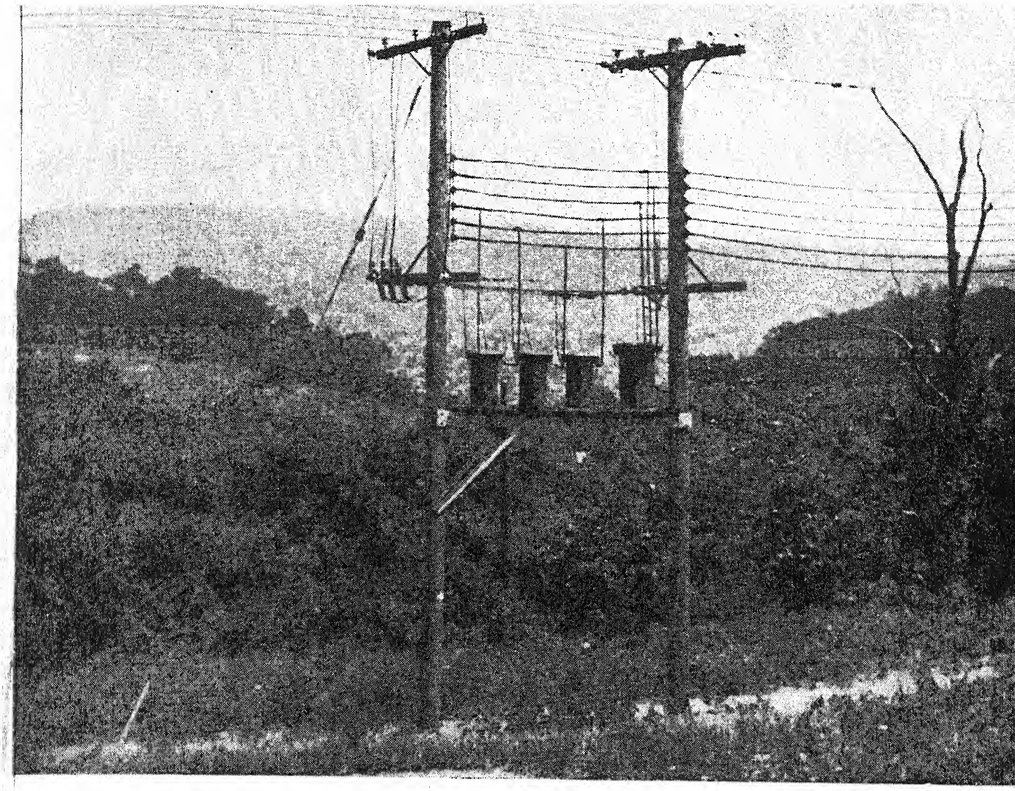
Prob. 41. Diagram a shunt motor with a starting box and a reversing switch. Show fuses in the main line to the motor. Check all circuits very carefully.

Prob. 42. If motor brushes "squeak," should they be oiled? Why?

Prob. 43. What harm does overloading do a motor or generator?

Prob. 44. Which produces the severest strain on a motor: starting, running, or stalling? Explain.

Prob. 45. Find the current to a 32-volt, 12-ampere motor, on a 120-volt line. How will the motor act now?



THE COUNTRYSIDE HAS LIGHT AND POWER

Lines stretch away in the distance, over hill and dale, from the far city to the pleasant rural sections. Here is a typical transformer bank to step down the 1100-volt service to a more useful 220-volt, three-phase power service and a 220–110-volt, single-phase lighting service for a modern farm district.

Fuses protect from line or load faults. Neat construction details give a high safety factor for continuous operation of the bank.

Without the transformer and alternating current, no such efficient step-down stations would be possible. The high losses of low-voltage transmission would make it impractical to operate such rural lines.

Chapter VII

POWER: ENERGY OF ELECTRONS

THE WORLD of commerce and industry is truly a world of power. Everywhere are evidences of increasing power plants. New transmission lines are threading across the hills, tying in new hamlets to the main power and lighting systems. Even the rural home has its radio and electric washing machine. The distant lumber mill has been electrified from the power station far down the valley at the falls. This wide use of power, in the real meaning of the word, makes it very necessary for all of us to know something about power in general, and about electrical power in particular.

107. **Man's Energy and Power.** To begin with, let us think about the work a man can do. The amount of work done depends on the weight of the material moved or changed, and on the distance it is moved. For example: Suppose a boy shovels and wheels a ton of coal up a 6-ft. terrace to a coalhole. How much work does he perform on this job?

Work = **pounds** × **feet,** answer in units of foot-pounds.

So work = 2,000 × 6 = 12,000 foot-pounds.

Another example: How much work does a boy do in lifting a 50-lb. box from the floor up to a table 3 ft. high?

Work = **pounds** × **feet,** or 50 × 3 = 150 foot-pounds.

Of course, the time required to do a piece of work depends on how fast it is done. To lift the 50-lb. box up to the table in ½ second would be much more difficult than doing it in 5 seconds. As a matter of fact, it would be 10 times as easy to do in 5 seconds as in ½ second (5 ÷ ½ = 10).

This is a common occurrence, experienced every day by all of us. Running up stairs in 6 seconds takes more "pep" than slowly walking up in 30 seconds — in fact, the faster rate requires 5 times the power that is used when the job is done slower.

To move an auto at 90 miles an hour takes at least 3 times the gasoline per hour that a 30-mile-per-hour speed demands. Many similar examples can be seen in our daily working experiences.

This same rule of energy and work and power applies to all kinds of electrical apparatus. For example, to light ten 60-watt lamps (½ ampere each on 120 volts) requires twice the power (watts) used by 5 such lamps. An elevator hauling 12 persons will draw about 4 times the power from the line to the motor as when the car carries only 3 people up the shaft. Doubling the speed up the shaft will mean doubling the power drawn from the supply line. This is quite obvious to anyone who has ever tried to "speed up" on a hard job, such as putting in coal or cutting a lawn on a terrace, or running uphill with a heavy load.

108. The Foot-Pound, Unit of Work. To make it easy to compare machines for their power, a standard unit of work must be used — the "foot-pound," as it is called. This is equally true for machines as for men or animals. For example, a locomotive pulling a train does work, and the turbine that drives the generator does work. The work done by anything is easy to find:

$$\text{Work} = \text{force (in pounds)} \times \text{distance (in feet)}.$$

This is sometimes written in a shorter form:

$$\text{Work} = FS, \text{ answer in "foot-pounds."}$$

Any engine or machine that exerts a force through a distance is doing work. Let us calculate the work done by a motor when it lifts an elevator load of 5,000 lb. up to a height of 90 ft.

$$\text{Work} = \text{force} \times \text{distance, or } FS$$
$$= (5{,}000 \text{ lb.})(90 \text{ ft.}) = 450{,}000 \text{ ft.-lb. answer.}$$

Can you find the work done by an electric engine that exerts a 60,000-lb. pull on a train for 50 miles?

There is only one caution to keep in mind in all work problems: **Measure the distance S along the path traveled by the force F in doing the work.**

109. The Horsepower, Unit of Power. "Work" and "power" are not the same thing, but are related. Power has the added item of time, along with the work done.

A horsepower is the "power" of an average horse to do work in a certain time. By measurements, this value has been found to be 33,000 foot-pounds per minute:

1 horsepower (h.p.) = 33,000 ft.-lb. per min., or
1 horsepower (h.p.) = 550 ft.-lb. per sec.

Now, if a motor actually must do 550 foot-pounds of work in 1 second, it must be a 1-h.p. motor, to carry its load successfully. But if twice as much time may be taken to perform this same job, then a ½-h.p. motor will be large enough for the task. However, if it must do the work in one half the time first allowed, then a 2-h.p. motor will be needed.

To Find Horsepower:

1. Find the work done per minute, and divide by 33,000; or
2. Find the work done per second, and divide by 550.

Examples: A motor must lift a 4,400-lb. load up a 75-ft. elevator shaft in 15 seconds. Find the horsepower required.

Solution: $\text{h.p.} = (\text{work per second}) \div 550$
$= [(4{,}400)(75) \div (15)] \div 550$
$= 40$-horsepower motor.

Again — suppose an electromagnet must lift 350 lb. of iron through 6 in. in 1 second. Find the horsepower used.

Solution: $\text{h.p.} = (\text{work per second}) \div 550$
$= [(350)(\tfrac{1}{2}) \div 1] \div 550$
$= .32$ horsepower.

Or, let us find the horsepower needed to draw the car up a 1,000-ft.-long incline in 8 minutes. The pull on the cable is known to be 18,000 lb. Here,

$\text{h.p.} = (\text{work done per minute}) \div 33{,}000$
$= (18{,}000 \times 1{,}000 \div 8) \div 33{,}000$
$= 68.2$ horsepower (about 70 h.p.)

From these examples you can see that power simply means the rate at which the work (in foot-pounds) is done. The calculation of work and power is easy if you keep in mind these simple facts about them.

110. Some Values of Power. There are many common examples of power that will help you to understand what power is. Examine Table XVII carefully.

111. How Time Affects Power. If a heavy-duty locomotive must double its speed, then the horsepower output of the engine must also be doubled. This is because, to do the same amount of work at twice the original speed, the engine will have to supply energy at twice the original rate. In other words, the

TABLE XVII. COMMON POWER VALUES

Machine	*Horsepower*
Locomotive — 24 drivers, Mallet type	5000
Ocean-liner engine, Diesel type	4000
Airplane engine, Wright Whirlwind type	200
Automobile engine, Ford V-8 type	90
Electric iron, 550-watt type, equal to	0.74 (¾)
Electric washing-machine motor	0.50 (½)
Electric refrigerator motor	0.33 (1/3)
Vacuum-sweeper motor	0.25 (¼)
60-watt Mazda lamp, equal to	0.08 (1/12)

(NOTE: 1 horsepower = 746 watts.)

foot-pounds per minute, or per second, will have to be just twice as great. The reverse is equally true; as the engine slows down to an easier speed, its energy (foot-pounds) is expended at a lower rate, which means a lower horsepower demand.

Therefore, a general rule can be set down for the effect of time on power:

1. To do the same work in less time requires more power.
2. To do the same work in longer time requires less power.

112. Other Forms of Energy. There are many kinds of energy in this world of ours besides mechanical and electrical energy. Some of these are so common that we often use or experience them without any thought about them. Table XVIII contains a list of energy forms.

TABLE XVIII. FORMS OF ENERGY

Form	*Unit*	*Source*
Electrical	Watt	Batteries; generators.
Mechanical	Foot-pound	**Force** acting through **distance.**
Thermal and radiant	B.T.U.; British Thermal Unit (Heat energy)	Flame; chemical action; radiation from a hot object, such as our sun or a hot stove.
Chemical		Chemical actions of all sorts.

Examine your day's work, and note the many widely different forms of energy: walking, running; thinking, writing, talking; breathing, moving, etc.

Two men in a restaurant order the same noonday lunch. One man goes back to his shop to cut pipe, to thread studs, and to do other mechanical work. The other man returns to his office to figure interest, to calculate bills, and to perform other mental work. Yet both men use similar energy sources.

Think of all the energy changes that take place between the coal pile out in the yard of a modern power plant and the current on the wires at the customer's building. The following is a partial list for this case.

TABLE XIX. ENERGY CHANGES

Place of Change	*Changed from*	*To*
Boiler firebox	Chemical energy	Heat energy
Boiler	Heat energy	Steam (heat)
Turbines	Mechanical (steam)	Motion (mechanical)
Generator armatures	Motion (mechanical)	Electrical energy
Generator fields	Electrical energy	Magnetic energy (flux)
Power line (losses)	Electrical (*IR* drop)	Heat losses, in line wires
Customer's motors	Electrical energy	Mechanical energy
Customer's heaters	Electrical energy	Heat energy
Customer's refrigerators	Electrical energy	Heat (or negative cold)
Customer's radio	Electrical energy	Sound, heat, mag., etc.

Dozens of more changes occur en route from coal pile to customer's electrical equipment, but those listed are the most important. Try to make a similar table of energy changes from the apple seed planted in the earth, to the energy in the boy's arm after he eats the tree's fruit years later. Many similar tabulated examples can be shown to prove to us what a really marvelous old world we live in.

113. The Watt, Unit of Electrical Power. We need a name and unit for electrical power (see Table XVIII). Neither the ampere nor the volt is by itself a true measure of electrical power. The unit needed is the watt.

A watt is the amount of electrical power used up when 1 ampere flows, under a 1-volt pressure, through 1 ohm of resistance.

Just as in a mechanical-power sense we have to multiply force by distance moved, so in the electrical-power sense we have the fact that

$$\text{Watts} = \text{volts} \times \text{amperes}$$
$$\text{or, } W = EI$$

This is commonly known as Watt's law. Compare it with Ohm's law. Following are the three forms of each:

Ohm's Law	Watt's Law
$E = IR$	$W = EI$
$I = E \div R$	$I = W \div E$
$R = E \div I$	$E = W \div I$

Notice that you can use the first form of either law, given above, to help you keep the other two securely in mind. Simply write the laws this way:

Ohm's Law	Watt's Law
$\dfrac{E}{IR}$	$\dfrac{W}{EI}$

To find E, I, R, or W from either of these laws, cover up the desired letter or quantity, and the other two will be in the correct relationship. Incidentally, this same idea can be applied to many other algebraic laws of the general form $X = YZ$, meaning that:

(One thing) = (a second thing)(a third thing).

When no sign ($+$, $-$, $\times$, $\div$) is shown between two letters, such as XY or EI, they are to be **multiplied**.

114. Measuring Watts by Ammeter-Voltmeter Method. An ammeter and a voltmeter, connected as shown in Figure 104, can be used to measure the watts "flowing" in the circuit.

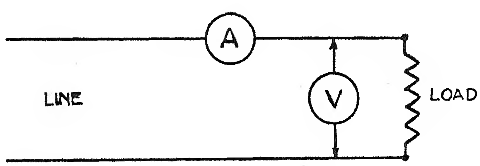


FIG. 104. Watts, by ammeter-voltmeter method.

Simply multiply the **volts** by the **amperes**, to get the power in watts, because

$$W = EI.$$

For example: If the ammeter reads 15, and the voltmeter shows 50-volts drop across the load, then

$$\text{Watts} = (\text{volts})(\text{amperes}) \text{ or } W = EI;$$
$$\text{So } W = (50)(15) = 750 \text{ watts. Answer.}$$

115. Watt's Law. Several very useful forms of Watt's law can be easily worked out by combining this law with Ohm's law. Here they are:

1. Watts = (volts)(amperes)
   or, $W = EI$.
   But, Ohm's law states that $E = IR$.
   So, we have $W = (IR)(R)$, or I^2R, which means

$$\text{Watts} = (\text{amperes})(\text{amperes})(\text{ohms}).$$

2. Again, $W = EI$.
   Ohm's law: $I = E \div R$.
   So we have: $W = (E)(E \div R) = E^2 \div R$, meaning that

$$\text{Watts} = (\text{volts})(\text{volts}) \div (\text{ohms}).$$

Thus, watts can be found in three ways:

$$\text{Watts} = W = \text{EI},$$
$$W = I^2R,$$
$$\text{and } W = E^2 \div R.$$

Examples:

1. A heater draws 5 amperes on a 110-volt line. Find the power, in watts.

   Solution: $\text{Watts} = W = EI$
   $= (110)(5) = 550$ watts. Answer.

2. A 30-ohm heater carries 4 amperes. Find the watts used up in its resistance.

   Solution: $W = I^2R$
   $= (4)(4)(30) = 480$ watts. Answer.

3. Find the power (watts) used in a 50-ohm resistor on a 250-volt line.

Solution: $W = E^2 \div R$
$= (250)(250) \div (50) = 1250$ watts. Answer.

116. Watts, Related to Horsepower. Many times we want to know the horsepower when the watts are given, or the watts when the horsepower is given. These results can be easily obtained, if we remember this fact:

1 **horsepower** = 746 **watts.**

Examples:

1. Find the horsepower needed to supply a heater that draws 14 amperes on a 250-volt line.

Solution: **Watts** = EI = (250)(14) = 3500 **watts.**
Horsepower = **watts** ÷ 746 = 3500 ÷ 746 = 4.7 horsepower. Answer.

2. Find the watts drawn from the power line by a motor using 8 h.p. of energy.

Solution: **Watts** = **(horsepower)**(746)
= (8)(746) = 5968 watts. Answer.

Similarly, you can solve such problems as this:

How much power (h.p.) is used by a household electric iron of 22 ohms on a 110-volt line? Try it. (Answer, .74 h.p.)

117. Rating of Lamps. Electric lamps and heating units are usually rated in **watts.** Perhaps, for lamps, a rating in units of **candlepower** would be better. But the present practice is to use **watts** for lamp ratings, and the general public has come to think in these terms.

Usually, lamps for home use, on 110 volts, are made in watt ratings of 10, 20, 25, 40, 50, 60, 75, and 100. The 10-watt size is for use in such things as piano lamps, pilot lamps in dark halls, etc. As the watts rating increases, the lamp gives greater light, or has greater candlepower, as we say. Hundred-watt lamps are used in such places as large kitchens, where the fixture is high overhead and yet must brightly illuminate the entire room.

THE SUCCESSOR OF THE STEAM LOCOMOTIVE
FAST ELECTRICS ARE REPLACING STEAM LOCOMOTIVES

These powerful engines are possible largely through the inventive and design genius of the electrical engineer and draftsman, bending quietly over a drawing board.

Look at these data on this beautiful giant: horsepower — 4800, delivered to 24 drivers; tractive effort — 66,000 pounds, at the drawbar; speed — 100 miles per hour, sustained at full load; length — 85 feet, in three articulated units; wheel base — 70 feet; rigid wheel base — 14 feet.

The 11,000-volt 25-cycle power coming down from the line through the pantograph, is reduced by transformers to 340 volts for her twelve 400-horsepower motors, and to 32 volts for all control circuits and train equipment. There are flexible-rubber drive connections between motors and main wheels.

The special cars behind this engine offer all the comforts of home, including a radio and public-address system, complete air conditioning, and fine indirect lighting — a herald of the new day in fast passenger trains.

Examine your own home tonight. Notice what sizes of lamps are used in your room lights, lamps, electric candles, etc. Should the hot lamp filament be shielded from direct view? Why? Try your hand at designing a "lamp" that throws the light down on the reader's book as he reads, comfortably seated in a deep-cushioned living-room chair. For such use, two 25-watt lamps, about 3 feet from the page, would supply just about the right amount of light. Is too much light bad for one's eyes? Yet can too little light be worse? Yes — and so we must always be careful about this matter of electric lamps as used in our homes, schools, offices, and factories.

For such uses as auditorium lighting, large halls where the lights are very high overhead, and street lighting, incandescent lamps of 1,000 watts up to 2,500-watts rating are commonly used.

Airport beacons and landing-lane "floodlights" are usually specially made 10,000- to 25,000-watt lamps. To glance at such a lamp when lighted, from only a short distance, would cause a very bad eye burn. For this reason, "shutters" are used on such lamps, so that only the beam of reflected light can be seen, and not the "hot spot" of the heated filament itself.

118. Total Watts in a Circuit. To determine the total power (watts) in a circuit, including all parts at the same time, simply add up all the watts in each part.

Example: Let us suppose in a certain house, at a certain time, six 40-watt lamps, three 25-watt lamps, a 17-watt toy transformer, a 550-watt electric iron, and a 65-watt curling iron are all being operated at the same time. What is the total power drawn from the line?

Solution: Total watts = sum of all the parts, in watts.

$$\text{Thus, Total Power} = (6 \times 40) + (3 \times 25) + 17 + 550 + 65$$
$$= 948 \text{ watts. Answer.}$$

This same simple procedure can be applied to all such cases where the **total power** is to be found.

If any part of the problem is given in **horsepower** instead of watts, it must be changed to watts, first, by using the fact that:

$$1 \text{ horsepower} = 746 \text{ watts.}$$

The **kilowatt** should be mentioned here as a bit of common knowledge among electrical workers.

1 kilowatt = 1000 watts.
Thus, 1,250 watts = 1.25 kilowatts, and
35.4 kilowatts = 35,400 watts.

119. The Watt-Hour and Kilowatt-Hour. Most power and light companies charge their customers for their electric service according to how much power is used (watts) and how long it is used (hours).

This metering could be done with an ammeter, a voltmeter, and an accurate clock. But the job would be very difficult if the power changed from minute to minute. If this method were used, the customer would have to figure as follows to get his bill in watt-hours:

1. Watt-hours = volts × amperes × hours,
   or $WH = E \cdot I \cdot H$.
2. Kilowatt-hours = (watt-hours) ÷ 1000,
   or $KWH = E \cdot I \cdot H \div 1000$.

So long as the current and voltage remain fairly constant over a long period of time, this method of getting the total WH or KWH is satisfactory.

Examples:

1. Find the KWH when a 550-watt electric iron is used for 6 hours.

   Solution: $KWH = WH \div 1000$
   $= (550)(6) \div 1000$
   kilowatt-hours = 3.3. Answer.

2. Find the KWH used when an electric motor that draws 35 amperes on a 250-volt line is operated continuously for 4 hours.

   Solution: $KWH = WH \div 1000$
   $= EIH \div 1000$
   $= (250)(35)(4) \div 1000$
   kilowatt-hours = 35. Answer.

120. The Watt-Hour Meter and Kilowatt-Hour Meter. A better way to keep account of the power consumed is by the use of a special meter designed to do what we had to do in the examples in Article 119.

The **watt-hour meter** and **kilowatt-hour meter** have three main parts:

a) Current coils, to measure the current in the line.

b) Voltage coils, to measure the voltage across the line.

c) A clock mechanism, to do the multiplying and recording.

These meters usually are made like small shunt motors. The motor field coils are **in the line,** and so they measure the **current,** like an ammeter. The armature coils are connected **across the line,** and so they measure the **voltage** like a voltmeter. The armature turns, then, in proportion to the **watts** being used. The shaft turns gears in a small clock mechanism that reads on dials directly in **watt-hours** or **kilowatt-hours.**

Examine the electric-power meter in your house. How can you tell whether the meter is "going"? Have somebody "plug in" an iron or some other heavy-power device, as you watch the meter. What happens? Why?

The large thin aluminum disk that turns between the poles of two large "horseshoe" magnets is a device to keep your meter accurate; this disk prevents the meter armature from running **too fast,** and also acts as a **brake,** to stop the meter as soon as the line current goes down to zero. **It is almost impossible for a KWH meter to overrate the actual power used.** In any case of meter fault, the meter will be bound to run **slower,** not faster.

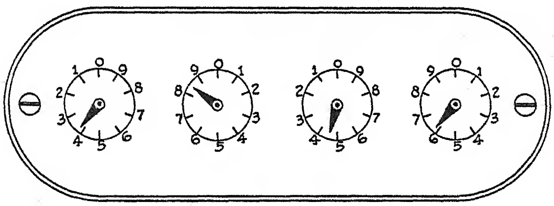


FIG. 105. Dials of a KWH meter, reading 3,846 KWH.

121. Reading the KWH Meter. Everybody should know how to read the house type of kilowatt-hour meter, the dials of which are easily read. Learn how to read your own meter, as a check on the electric-power bills for your house or store.

Most *KWH* meters have four dials, arranged as shown in Figure 105. Each dial takes care of one of the figures in a four-

figure number, such as 2,943 or 3,218. The dials are so arranged that they read **left to right,** the same as we commonly read numbers. The reading shown on the "register" in Figure 105 is 3,846 kilowatt-hours.

To Read the KWH Meter: Simply read each dial in order, the one at the left end first, and so on, to the right-end dial. Read each dial thus: **the largest number the hand has passed.**

Try reading your own electric meter now. Be careful to read each dial correctly, then set down the dial readings in order. Make a sketch like Figure 105, and show the hands reading 6,748 *KWH*. Let us call the extreme left-hand dial *A*; the other dials following in order *B*, *C*, and *D*. Then, your sketch must show the hands thus:

Dial	Hand Position	
A	between 6 and 7	(should be at 6.748)
B	between 7 and 8	(should be at 7.48)
C	between 4 and 5	(should be at 4.8)
D	between 8 and 9	

Reading will then be 6,748 *KWH*.

122. The Monthly Power Bill. Now that you can read your electric meter in *KWH*, you can easily check your monthly power bill in *KWH* used during the month.

Two meter readings are necessary: one at the first of the month and one at the end of the month. By subtracting these, you get the power in *KWH* used during the month.

Example:

Suppose the meter in a house read thus:

May 1 — 2,784 kilowatt-hours.

May 31 — 3,092 kilowatt-hours.

Find out how much power (*KWH*) had been used, and the cost at 6 cents per *KWH*.

Solution: $3092 - 2784 = 308$ kilowatt-hours. Answer.

At 6 cents per *KWH*, this power would cost:

$(308)(.06) = \$18.48$. Answer.

SUMMARY

Work = (force, in pounds) × (distance, in feet).

Unit of work is the foot-pound, ft.-lb.

Power = ability to do work, or rate of doing work.

Horsepower = 33,000 ft.-lb. per minute, or
= 550 ft.-lb. per second.

To find horsepower:

$$\text{H.P.} = \frac{(\text{lb.})(\text{ft.})}{(\text{min.})(33{,}000)}, \text{ or } \frac{(\text{lb.})(\text{ft.})}{(\text{secs.})(550)},$$

where minutes or seconds = time used to do the work.

To do a certain piece of work in:
Less time requires more power.
Longer time requires less power.

Energy has several common forms: electrical; mechanical; thermal (heat); chemical.

Watts (unit of electrical power) can be found thus:
$W = EI$, or I^2R, or $E^2 \div R$.

Horsepower to watts:
1 Horsepower = 746 Watts.

Total watts = sum of the watts of each part.

Kilowatts = watts ÷ 1000.

Kilowatt-hours = (kilowatts) × (hours).
Watt-hours = (watts) × (hours).

PROBLEMS

Prob. 1. Find the work a grocer must do to put six 100-pound sacks of sugar up on a 4-ft.-high platform.

Prob. 2. Calculate the work done by slaves in getting the top block of sandstone (6,500 pounds, roughly) in place on a 250-ft.-high pyramid. (No wonder many of these miserable slaves fell dead from sheer exhaustion.)

Prob. 3. If this work (Prob. 2) was done by 350 slaves, chained in a long line to pull ropes, find each slave's work.

Prob. 4. A job requiring 75,600 ft.-lb. of work, must be completed in 3 minutes. Find the work per minute. Find the horsepower needed.

Prob. 5. To do the task of Problem 4 in 20 seconds will need how much horsepower? Why the increase in power?

Prob. 6. Find the horsepower where 950 pounds of steel must be hoisted at a rate of 5 ft. per second.

Prob. 7. What size motor must be used (h.p.) to "crank" an engine that requires work done at the rate of 685 ft.-lb. in 2 seconds?

Prob. 8. To do the job of Problem 7 in .2 seconds, what horsepower will be needed?

Prob. 9. If a man's power is ⅛ h.p., find his rate of work.

Prob. 10. How long should it take Problem 9 man to lift 6 tons of coal up over a 4-ft. terrace? Do not count rest time.

Prob. 11. Suppose a 150-lb. boy climbs straight up a 6-ft. ladder in 8 seconds. Find the h.p. his legs supply.

Prob. 12. Why does Problem 11 boy tire? Will a slower speed reduce his fatigue? Why?

Prob. 13. Explain, in the light of this chapter, why an overloaded motor heats up rapidly. Is extra cooling sufficient remedy?

Prob. 14. Which takes the most fuel per mile: a 3500-lb. auto, or a 2500-lb. auto? Why? Carefully explain in terms of **work.**

Prob. 15. Make a table of the **energy changes** in a water-power system, from the water in the ocean to the current in the power line.

Prob. 16. Why is our sun the real "first" source of all our energy?

Prob. 17. Find the power in watts used in a heater that draws 8.5 amperes on a 110-volt line.

Prob. 18. What power is used by a 55-ohm heater on 220 volts?

Prob. 19. Compare these heaters for power used: No. 1 takes 6 amperes on 120 volts; No. 2 has 31 ohms and operates on 150 volts.

Prob. 20. To consume equal power, what resistance should No. 2 unit of Problem 19 be?

Prob. 21. Find the watts consumed in a 65-ohm resistor carrying 1.8 amperes. What form will this energy appear in? Why?

Prob. 22. What current must flow to consume 425 watts on 110 volts.

Prob. 23. Find the current in a 30-watt lamp on 110 volts.

Prob. 24. Find the current output of a 7-watt transformer, at 10 volts.

Prob. 25. How many watts will Problem 7 motor require?

Prob. 26. How many watts will Problem 8 job require? Why the change?

Prob. 27. How many watts equal the man's power in Problem 9?

Prob. 28. What horsepower does an 800-watt iron use? The newer "automatic" electric irons are this size.

Prob. 29. Why are most rivers unsuitable for power dams?

Prob. 30. Why does "coal-steam-electric" power cost more than water power? Do power dams cost much?

Prob. 31. Why must power dams be high? Why are canyons used as dam projects? How does the dam height affect the power that is developed?

Prob. 32. Find the power lost in a 65-mile, 11,000-volt transmission line, carrying 150 amperes. The *IR* drop of the line is known to be 1250 volts.

Prob. 33. Find the kilowatt consumption of a 75-h.p. motor.

Prob. 34. Calculate the h.p. in a *KW* of electrical energy.

Prob. 35. Find the total *KW* of two 25-h.p. motors, a 60-h.p. motor, and 16,900 watts lighting load in a store.

Prob. 36. If the total load of Problem 35 operates steadily for 8 hours, find the *KWH* used.

Prob. 37. At 6½ cents per *KWH*, find the cost of doing a 5-hour ironing with the electric iron of Problem 28.

Prob. 38. Find the cost (at 6½ cents per *KWH*) of using an electric washer (½-h.p. motor) for 4 hours continuously.

Prob. 39. At 5 cents per *KWH,* find the operating cost of a small electric refrigerator, for 30 days, if its ¼-h.p. motor runs one third the time, as in warm weather.

Prob. 40. What does the "mistake" of leaving a 40-watt lamp burn overnight (7 hours, say) cost at 6 cents per *KWH*?

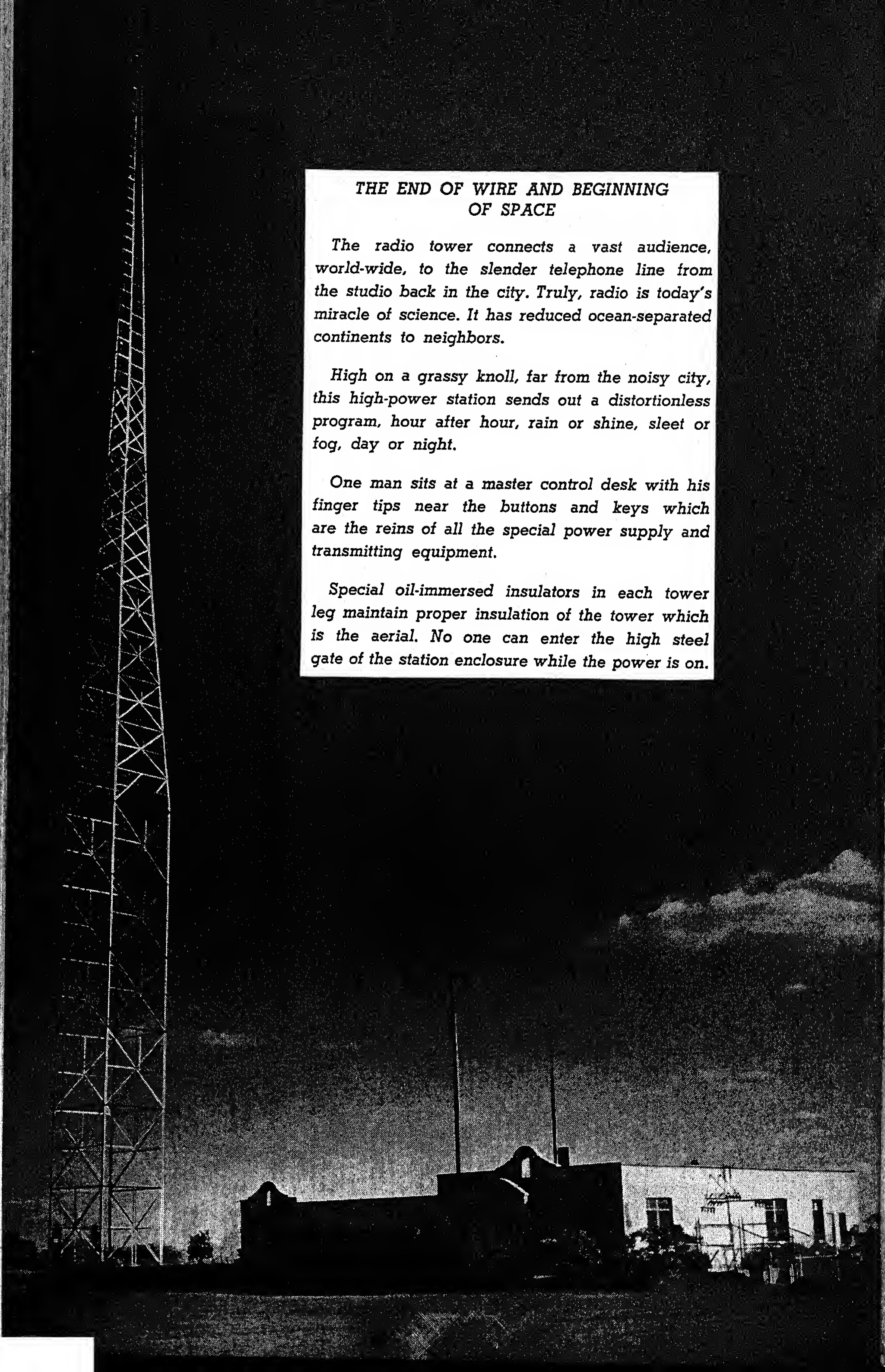
Prob. 41. Why does an electric stove cost more to use in a "coal" region than in a water-power area?

Prob. 42. What advantages has a central power plant over the individual power plant?

Prob. 43. Are these advantages worth anything, in "dollars and cents," to the power-line customer? Why?

Prob. 44. Who really "pays" for the power lost in a transmission line? Can long lines be very efficient? Why?

Prob. 45. Estimate your home's electric bill for this month. Be careful to count the *KWH* of lights, radio, iron, curler, toaster, etc. Omit nothing used very often, or your estimate will not be fair.



THE END OF WIRE AND BEGINNING OF SPACE

The radio tower connects a vast audience, world-wide, to the slender telephone line from the studio back in the city. Truly, radio is today's miracle of science. It has reduced ocean-separated continents to neighbors.

High on a grassy knoll, far from the noisy city, this high-power station sends out a distortionless program, hour after hour, rain or shine, sleet or fog, day or night.

One man sits at a master control desk with his finger tips near the buttons and keys which are the reins of all the special power supply and transmitting equipment.

Special oil-immersed insulators in each tower leg maintain proper insulation of the tower which is the aerial. No one can enter the high steel gate of the station enclosure while the power is on.

Chapter VIII

ALTERNATING CURRENTS: REVERSING ELECTRONS

WHAT is true of direct current and d.c. circuits, also is true of alternating current and of a.c. circuits. In addition to all these similar facts of d.c. and a.c., a few things about a.c. are especially true of a.c. alone. These special differences are just the things that have brought a.c. into wider and greater use than d.c. power has ever had. In fact, the future of a.c. is, at present, far greater than the future of d.c. Because of this, some of these more important differences are to be discussed here.

124. The Difference Between D.C. and A.C. Direct current never changes its direction of flow; it always flows in the same direction in the circuit. This is not true of a.c. Alternating current, as the name implies, alternates or reverses, regularly and evenly, in the wires of the circuit. In most cities, power systems operate on a frequency of 60 cycles per second. This means that 120 times a second the current reverses in the wires of the circuit. It flows first one way in the wires, then reverses and flows in the opposite direction, and so on, thus making what we call an **alternating current.** Of course, to do this, the **voltage** also must be alternating.

125. Cycles and Frequency. These two terms need to be clearly defined, here, so they may be used from now on in various discussions and explanations. The curve of an alternating current, shown in Figure 108, practically tells the whole story graphically. (Compare Fig. 108 to Fig. 69 in Chapter V.)

Suppose a power line operates on a frequency of 60 cycles per second. What does this mean? It means that:

1. The line is an a.c. line and not a d.c. line.
2. In every second, the current reverses or alternates through 60 cycles or 120 alternations.

3. All these alternations are exactly evenly timed.
4. As much current flows in one direction in the lines as flows in the opposite direction.
5. All equipment operated on this line must be designed to operate on "60 cycles, a.c." This is especially true for motors, all transformers, and all electric clocks.

These two definitions verbally explain the terms:

Cycle — a cycle is one complete "wave" of the a.c. curve, and always has two **alternations** in it, as shown in Figure 108.

Frequency — the frequency of an alternating current is always given in the number of **cycles per second** that the current makes. From Figure 108, you see that the cycles per second are always **half** the number of alternations per second (reversals per second) of the current.

These terms apply to both voltage and current on an a.c. line.

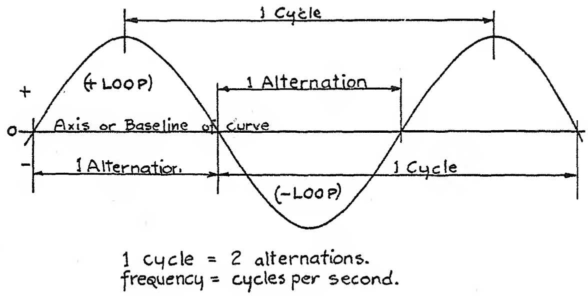


FIG. 108. A.C. wave; alternations, cycles, and frequency.

126. Alternations. Refer to Article 78, in the chapter on generators, to review how an alternating current develops in a generator. You will remember that, when the armature turns the wires past an *N* field pole, the current is generated in the opposite direction to that produced when the wire is moved past the *S* field pole.

It should now be clear that a 2-pole generator will produce 2 **alternations** in the armature, every complete revolution; a 4-pole machine will have 4 **alternations** per revolution; and so on.

Every pair of alternations is a **cycle.** So, a 2-pole machine has 1 **cycle** per revolution and a 4-pole machine has 2 **cycles** per revolution. Therefore, the speed (revolutions per second) of the machine armature will govern the cycles per second, or frequency, of the generated current.

127. The Alternator, or A.C. Generator. Alternating-current generators are usually called **alternators** "for short." Alternators are used extensively because of the common use of a.c. for large power systems.

The next time you pass a power-generating station, especially a central power station, look in the windows at the large alternators. Notice the heavy concrete mounting foundations under the generators, their neat appearance, and steady hum as they whirl at a constant speed. Perhaps the station operator will let you into the station, under his care and guidance, for a closer look at the generators.

128. Parts of the Alternator. Alternators are like d.c. generators in most of their details and parts. The two most important things to notice about an alternator are:

1. **The alternator has no commutator; it has only slip rings.** See Articles 79 and 81 for details of "slip rings."
2. **The field of an alternator is always separately excited, from a special d.c. source.** Sometimes a small d.c. shunt generator is run on the same main-drive shaft as the turbine and the alternator, to supply the large alternators' field current.

Otherwise, the parts and general construction of the alternator are quite similar to regular d.c. generators. See Article 82, on "Parts of a D.C. Generator," for details.

Usually, the alternator is made with a many-poled revolving field and a stationary armature. The reason is simply one of lower cost and better construction, this way, than when the field is stationary and the armature revolves. Two slip rings are used to get the d.c. into the rotating field.

Figure 109 shows the general ideas of most alternators. The more field poles there are, the more alternations the current will have per revolution of the field. This modern a.c. generator, or alternator, operates on the same principle as Experiments 27 and 28. Review your data on these experiments.

129. Speed of the Alternator Affects Frequency. It is clear, from Article 126, that two things affect the frequency of any alternator:

1. **Number of field poles.** If the speed of the alternator remains the same, then a larger number of field poles (in *N–S* pairs) will cause a larger number of cycles per revolution. Therefore, more field poles will develop a higher frequency in the generated current.
2. **Speed (revolutions per minute).** Of course, if the speed of the machine increases, more poles will pass a wire in every second. Therefore, the frequency will be greater.

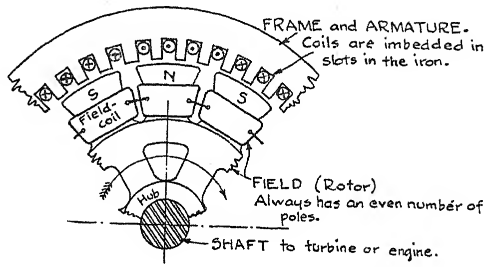


FIG. 109. A rotating-field-type alternator.

130. Why Frequency Should Be Constant. Many electrical machines must have a constant frequency a.c. power source to operate properly. The most recent and most common of such devices is the electric clock used in many homes. To keep exact time, an electric clock must have an absolutely constant frequency a.c. source.

Therefore, when many such devices are in use on a power company's lines, the company must somehow always keep the line frequency the same. A "60-cycle line" must always be kept at exactly 60 cycles per second.

131. Heating Effect of A.C. A resistance gets hot when it carries current, regardless of the direction of flow of that current. Therefore, the heating effect of a.c. is similar to that of d.c. Thus, electric stoves, toasters, irons, lamps, etc., get just as hot and give as much heat or light on a.c. as on d.c., so long as the voltage is the same in both cases.

However, this does not apply to other electrical apparatus, such as motors. Motors, for example, are made especially for use on a particular line, a.c. or d.c. This should be remembered.

132. What an Alternating Voltage Means. When we say a line is 110-volts a.c., what is really meant? First of all, from Article 125, it is known that an a.c. is a constantly changing voltage. So, at every instant the voltage on an a.c. line is different than it was an instant previously. This is shown by the a.c. curve in Figure 110.

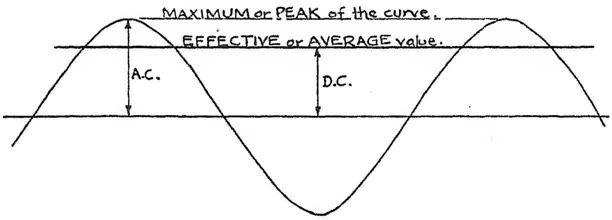


FIG. 110. The meaning of an a.c. voltage.

By some special experiments, it was found that a.c. and d.c. voltages compare as follows (referring to Fig. 110):

Maximum a.c. voltage = (1.41) (d.c. voltage giving the same results).

D.C. voltage = (.707) (a.c. voltage giving the same results).

Thus, to give the same results as a **100-volt d.c.** power source, the a.c. line must have

(1.41) (100) = 141 **volts, maximum.**

But such an a.c. line would be called 100-volts a.c., because it is equal to 100-volts d.c.

Therefore, you can see that an a.c. line is rated in **voltage of an equal power, d.c.**

133. What an Alternating Current Means. What was said in Article 132 about an alternating voltage, also can be said about an alternating current.

An illustration of an alternating current would look like Figure 110 in all respects. The equations to show how equal alternating and direct currents compare are:

Maximum alternating current = (1.41) (direct current giving the same results).

D.C. $= (.707)$ **(a.c. giving the same results).**
Thus, to give the same results as 100 amperes d.c., an alternating current would have to be

$$(1.41)(100) = 141 \text{ amperes, maximum.}$$

But such an alternating current would be known as 100 amps. d.c., because it is equal to 100 amperes d.c.

Therefore, as in Article 132, an a.c. power source is always rated in terms of an equal d.c. power. This makes comparisons between a.c. and d.c. easy, because

100-amps. a.c. = 100-amps. d.c.,
100-volts a.c. = 100-volts d.c.,
100-watts a.c. = 100-watts d.c.,

and so on.

134. A.C. Is Not Used for Electroplating. The reason for this is quite obvious to the student. Remember that an a.c. reverses its flow at regular intervals. Therefore, when used for a power source in electroplating, a.c. will plate during one alternation, and then, during the next alternation, it will clean off what it plated before. The total result, of course, would be that no plating could be done with a.c.

135. How to Recognize A.C. from D.C. The majority of power companies, for certain economic reasons, furnish a.c. to their customers. Consequently, most of our city homes have a.c. power delivered to them over the local power plant's lines.

Batteries and d.c. generators always deliver d.c. You can easily tell a d.c. generator if, upon examination, you find it has a commutator. Only d.c. generators have commutators. Most small generators (12 by 8-in. base) are d.c. machines; a.c. machines are rarely made in small sizes.

Transformers and spark coils all deliver alternating current. Transformers must be operated on a.c., but spark coils may be operated on either a.c. or d.c., although d.c. is the most satisfactory. Following are several experiments to show up the great difference between a.c. and d.c. Try them out; keep a record of your findings.

Experiment 45. Testing for a.c. by electrolysis. Materials needed: a water glass; a 110-v. lead to a 110-v. source.

The glass should be half filled with water, to which 5 drops of sulfuric acid are added (poison — see Art. 62).

Push the bare ends of the 110-volt leads through a cork, so they cannot accidentally touch and "short" the line. Plug the leads into a 110-v. a.c. socket, and dip the cork-separated bare wires into the electrolyte. **Do not get the cork wet,** or you may get a shock.

Do bubbles form at both wires? Equally? What is happening to the water? (Water is made up of hydrogen [2 parts] and oxygen [1 part], so what would you expect water to break down into, under "electrolysis"?)

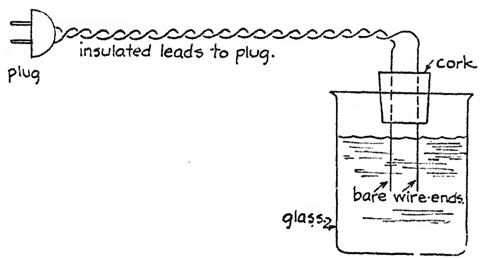


Fig. 111. Testing for a.c. by electrolysis.

When this test is used for d.c. or a.c., the kind of current in the line can be found as follows:

A.C. produces an equal amount of bubbles at both wires.

D.C. produces more bubbles (hydrogen) at the —wire; the other wire has less bubbles, if any (oxygen). Review Article 40 with Experiments 18 and 19 on electrolysis.

Experiment 46. Testing for a.c. with a potato. Materials needed: half of a raw potato; the same plug, lead, and cork arrangement as used in Experiment 45.

Do not let the bare leads touch, or "short." Do not touch the bare wires with your fingers, either. If the bare wires touch, a short circuit will occur, blowing the main fuse. If your fingers touch both bare wires at the same time, you may be severely shocked.

Push the bare wires about ¼ in. into the half potato. Plug the leads into the power circuit. You will now be able to tell if the line is a.c. or d.c.

A.C. will cause a green spot to appear around both wires.

D.C. will cause a green spot around only the +wire.

Experiment 47. Testing for a.c. with a lamp and magnet. Materials needed: a loose-filament type of lamp in some socket; a large bar or horseshoe permanent magnet.

Turn on the lamp, and bring the bar magnet up to the glass bulb. If the lamp filament is being lighted from an a.c. source, the hot filament will vibrate rapidly. This effect is plainly visible, and only exists when a.c. is used. **Two lamps, connected in series, make it easier to view the results with the naked eye.**

Can you explain why the a.c. filament vibrates? Why does not d.c. produce this peculiar effect? Make a neat sketch of the way you performed this experiment.

Experiment 48. Testing for a.c. with an electromagnet. Materials needed: a small electromagnet; a toy transformer or a 25-watt lamp and lamp socket; an empty tin can or a flat piece of tin.

Energize the electromagnet from the toy transformer, at about 6 volts, or —

Connect the electromagnet in series with the 25-watt lamp, on a 110-volt a.c. line. Be careful to avoid all shock.

Bring the tin near the magnet pole. Is the "pull" constant, or does it "vibrate"? Why? Will the magnet, on a d.c. source (batteries) give a steady pull? Why?

The simple buzzer made in Experiment 14 can be operated nicely on a.c., without using the breaker. Merely connect the **coil ends** to the a.c. transformer as in this Experiment 48. The tin armature will vibrate 120 times a second on a 60-cycle line. Why?

If your doorbell operates on a special doorbell transformer, it does not need a breaker on the armature. It will give a clearer tone and operate better if the breaker is "shorted out" and the magnet coils are connected directly to the line.

136. Why a 60-Cycle Lamp Does Not Flicker. There are two reasons why lamps on our 60-cycle a.c. house-lighting circuits do not flicker.

True, there are 120 alternations per second on such lines, but they come and go so fast that the eye does not notice any change in light. Any frequency over about 40 per second is quite invisible to the human eye. Of course, you know that this fact makes our modern movies possible.

But even if the eye could "see" such a rapid change, the white-hot lamp filament does not entirely cool off during the very short time the current is low. The lamp filament does not cool off rapidly enough to be "down," before the new alternation comes along the line to heat it up again.

Around Niagara Falls most a.c. power and light circuits are "25 cycles" or 50 alternations per second. Many visitors to the Niagara Falls area, who have been used to 60-cycle lines at home, can vaguely sense a sort of flicker in the lights the first few days they are in that vicinity.

Look up the word "stroboscope." Then find out how you can make a simple stroboscopic top from a 3-in. cardboard disk on a short lead pencil. This top will show up the otherwise invisible flicker in your a.c. lamplight.

137. Transformers. One of the greatest advantages of a.c. over d.c. is that, on a.c., voltage and current changes from low to high, or from high to low values, can be made very efficiently by using transformers. On d.c. lines, the only change that can be made is from a high value to a lower value. And even this change, on d.c., is very inefficient, the energy really being "cut down" in a resistor that wastes the rest of the line energy in heat.

Where transformers can be used (only on a.c.), this change-over can easily be made at about 98 per cent efficiency. For example: suppose a power company wishes to send 10,000 watts (or 10 *KW*) to a customer who wants this power at 200 volts. How can transformers be used to help solve this power problem and keep down "line losses" (*IR* drop)? First of all, figure the customer's current:

$$W = EI;\ \text{so } I = W \div E$$
$$I = 10{,}000 \div 200 = 50 \text{ amperes.}$$

Suppose the power line has a resistance of 6 ohms. How much voltage will be lost in this line?

Solution: $E = IR$; $E = (50)(6) = 300$ volts.

Therefore, to deliver the desired 200 volts at the end of the line, the power station must have a voltage of

$300 + 200 = 500$ volts, total.

It is quite obvious that such operation is very wasteful. But what can be done about it, by using transformers?

You will have to consider another fact about transformers right here, namely, that when a transformer lowers the voltage, it automatically raises the current in the same ratio. The watts remain the same. With this as a basis, "figure" the line as an a.c. line, thus:

1. Generate the power (10,000 watts) at 200 volts, 50 amperes.
2. Raise the voltage to, let us say, 2,000 volts on the line. The line current will then be only 5 amperes. Reason:

$$\frac{200}{2000} \times 50 = 5; \text{ also: } 10{,}000 \div 2000 = 5 \text{ amps.}$$

3. Send this 10,000 watts (2,000 volts, 5 amperes) to the customer.
4. At the customer, use another transformer to lower the 2,000 volts to the desired 200 volts. The current will then be again 50 amperes.
5. Figure the "line drop": $E = IR$; $E = (5)(6) = 30$ volts drop.

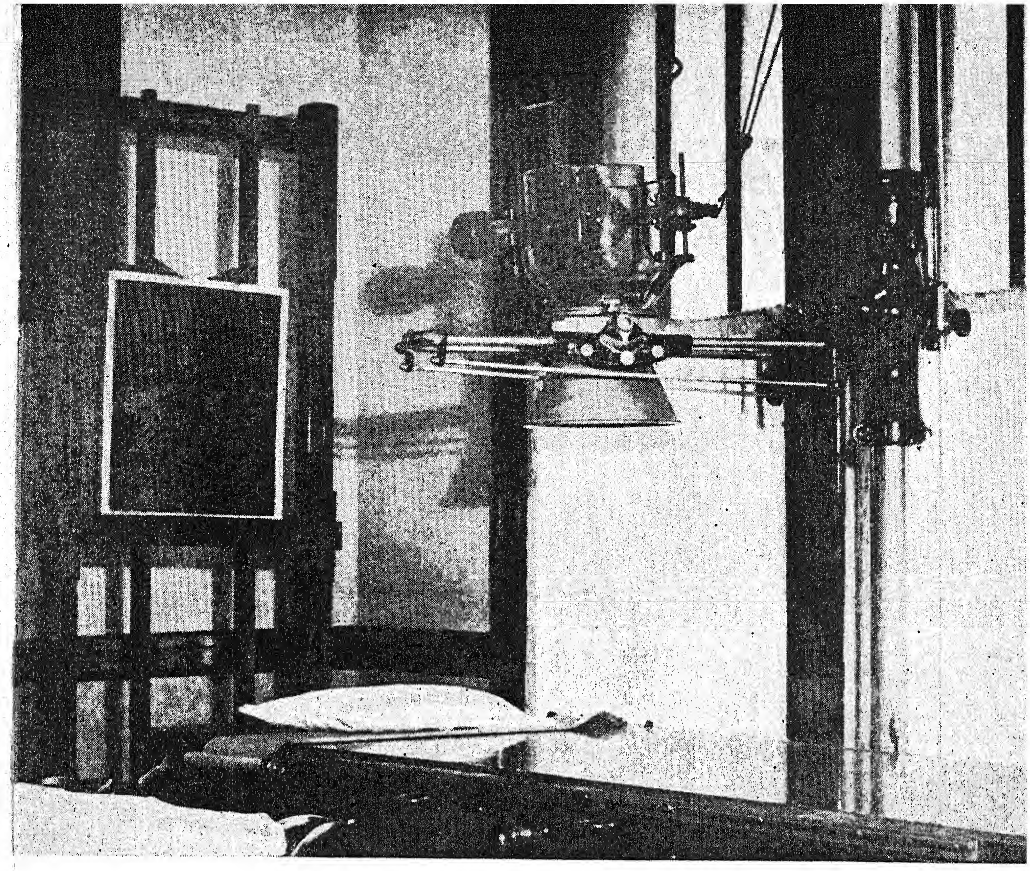
   (These calculations assume 100 per cent efficiency on all transformations.)

Thus, it is seen why power companies have changed from d.c. to a.c., with its advantage of using transformers.

Some of the commoner uses of transformers are listed in Table XX. Can you add to the list? Look about you for new uses of this very valuable piece of a.c. equipment.

TABLE XX. TRANSFORMERS AND THEIR USES

Type	*Use*	*Voltage Change*
Substation	Steps up voltage for the power line	500 v. up to 11,000 v.
Distribution	Steps down line voltage at customer	11,000 v. down to 500 v.
Toy transf.	Steps down 110 v. for use on toys	110 v. down to 20 v.
Bell transf.	Steps down 110 v. for use on doorbell	110 v. down to 8 v.



THE ELECTRON BECOMES THE PHYSICIAN'S ASSISTANT

The Coolidge tube has been so far developed that it is in common use in the general practitioner's office. By its all-penetrating rays, this electrical device sees the deeply hidden trouble, and often can remedy it without surgery.

Heavy leaded glass shields and lead-lined directing cone protect both patient and operator from rays extraneous to those desired.

Special automatic timing equipment provides exact exposure limits for picture, fluoroscopic view, or treatment.

This tube requires 30 milliamperes, at 65,000 volts for operation. It is a self-rectifying type, using a.c.

Spark coils, such as are used on automobiles for ignition, also are a common type of transformer. But ordinarily this type must in some way be supplied with a "broken up" or interrupted d.c. in the primary coil, unless operated on a special a.c. line. The usual way of supplying this interrupted d.c. is by the use of a simple buzzer-breaker, such as that on a common doorbell. The old Ford spark coil used this vibrator scheme to break up the d.c. from the battery to the coil primary circuit.

138. Parts of a Transformer. All transformers have two essential parts, consisting of the coils and a soft iron core.

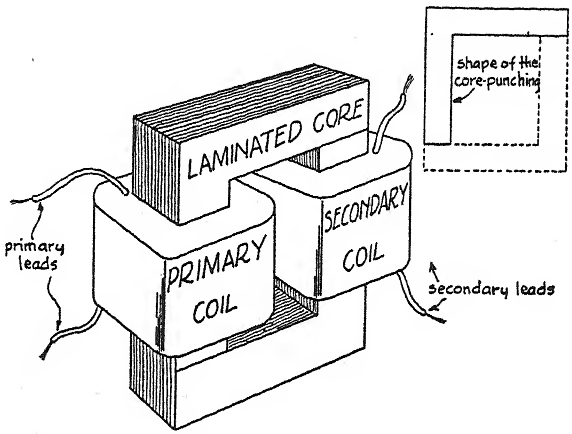


FIG. 112. A standard type of transformer.

The primary coil brings the power in to the transformer. This coil must be wound with insulated wire, heavy enough to carry the input current. The rating of the primary is in watts — $W = EI$.

The secondary coil brings the power out of the transformer. This coil, also, must be wound with insulated wire, heavy enough to carry the output current. The rating of the secondary also is in watts.

The primary watts = the secondary watts.

The core of the transformer always is laminated, and always is made of soft iron, either strips bent to the needed shape, or punchings or iron wire. Of course, all such laminations should

be insulated, to serve their purpose of stopping the eddy currents in the core.

The primary and secondary coils are wound on the iron core. The iron permits a denser or stronger flux than is otherwise possible. The two coils and the iron core must be thoroughly insulated from each other. Figure 112 shows the schematic idea of a transformer.

Sometimes transformers have the primary and secondary coils wound on top of each other, or side by side. But the usual type of construction is that shown in Figure 112.

Most transformer coils are wound by machine, on rectangular coil forms made of heavy fiber or asbestos board. These coils are then put on the laminated core, and the whole assembly is solidly mounted on a baseboard or in a case, for protection.

Transformer leads are usually brought out to threaded terminal bolts for ease of connection.

139. How a Transformer Works. In many ways, a transformer acts like a generator, although a transformer has no moving parts.

Whenever a wire or a coil is "cut" by flux, a current is set up in the coil that is so cut. In a transformer, however, this idea is carried out in a very simple way, without moving any of its parts.

The primary coil has an a.c. wave in its turns. This causes an alternating flux to be set up in the iron core. This flux also passes through (cuts) the secondary coil. The core is arranged so that this happens.

When the secondary coil is cut by the flux, a current is set up in the coil. If the flux just grew from zero up to a certain value and then remained constant, the secondary current would have only one "spurt," and then die down to zero. Unless the flux is always changing, and the secondary coil is constantly "cut" by a changing flux, the coil will not have any generated voltage in it.

But, when the constantly changing flux from the a.c. operated primary coil cuts the secondary coil, a constantly changing voltage is set up in this coil. This secondary voltage and current will be the same frequency as the primary circuit. Thus, on a 60-cycle line, a toy transformer will deliver 60-cycle power from its secondary terminals.

The voltage change-over will be in direct proportion to the turns on the coils, by this formula:

$$\frac{\text{Primary turns}}{\text{Secondary turns}} = \frac{\text{primary volts}}{\text{secondary volts}}$$

The current change-over in a transformer will be in inverse proportion to the coil turns, thus:

$$\frac{\text{Primary turns}}{\text{Secondary turns}} = \frac{\text{secondary amps.}}{\text{primary amps.}}$$

Remember these two relations about transformers. Examine the following example of their use in a problem.

Example:

Suppose a power-line transformer is used to step the 11,000 volts down to 110 volts. The primary winding has 121,000 turns. Secondary current is to be 500 amperes.

Find: Secondary turns; primary amperes.

Solution:

$$\frac{\text{Pri. Turns}}{\text{Sec. Turns}} = \frac{\text{Pri. Volts}}{\text{Sec. Volts}};$$

$$\frac{121{,}000}{X} = \frac{11{,}000}{110}, \text{ or } X = \frac{121{,}000 \times 110}{11{,}000}$$

So X must be 1210 **turns.** Answer.

$$\frac{\text{Pri. Turns}}{\text{Sec. Turns}} = \frac{\text{Sec. Amps.}}{\text{Pri. Amps.}};$$

$$\frac{121{,}000}{1210} = \frac{500}{A}$$

$$\frac{100}{1} = \frac{500}{A}$$

So A must be 5 **amperes.** Answer.

How does all this check with the statement that

Primary watts = secondary watts?

Well, Primary watts = (Pri. Volts)(Pri. Amps.)
= (11,000)(5) = 55,000 watts.
Secondary watts = (Sec. Volts)(Sec. Amps.)
= (110)(500) = 55,000 watts. Check.

Reread this example, and notice how simple it really is.

140. Experimental Transformer. Some very interesting transformers may be built of enameled or cotton-covered copper wire, which can be obtained at a moderate cost. Such a project will teach you more things about a transformer than you can learn from many books. The spark coil and small "step-down" transformer will be used in other experiments later.

Experiment 49. Making a 15-watt step-down transformer. (Primary voltage, 110-v. a.c.; secondary, 7 volts, 2 amps.) Materials needed: heavy cardboard or red fiber for the coil form; 30 tin strips, ⅝ by 8 inches long, cut from tin cans, for the core laminations; No. 30 enameled wire for the primary coil; No. 20 double-cotton-covered wire for the secondary coil; 4 binding posts; insulating tape; shellac.

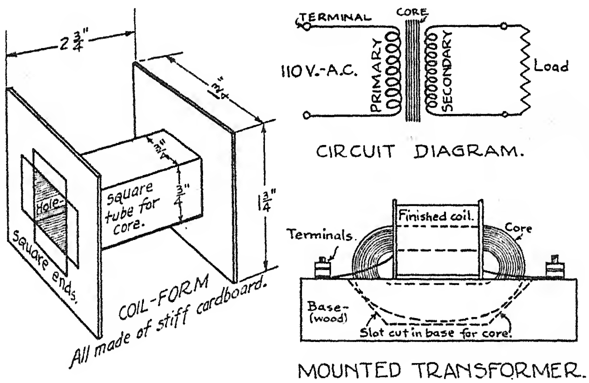


FIG. 113. Coil form for small step-down transformer.

First, make a coil form, as shown in Figure 113, out of heavy stiff cardboard or stiff red fiber. Cut both coil ends alike. Make the center tube ¾ in. square, all in one piece, with tabs on each end to fold up and glue to the end pieces when in place. Make a neat job of this coil form.

Make a small hole in one coil-form end, at the tube corner. Put about 8 in. of the No. 20 double-cotton-covered secondary wire through this hole, and begin winding on the secondary winding. **The secondary winding must be 150 turns, No. 20 d.c.c. wire.** The end of the winding may be brought out through a hole in the coil-form end. Bring both low-voltage leads out on the same end of the coil. Be careful to make all windings in smooth even layers, with no overlapping turns. Now, tape this secondary winding with a single layer of tape.

Now, the primary (110-v. a.c.) can be wound in place, using the No. 30 enameled wire. **The primary winding must have 2,200 turns,** evenly wound in smooth layers. Be sure the end turns (near coil-form ends) do not "slip over the brink" and get wedged down in a crevice or crack. The ends of the winding must be brought out on the other end if the coil from the low-voltage leads. Cover this primary winding with tape, to both insulate it and protect it from damage.

Shellac the 30 tin-can-iron strips; remember, all laminations must be insulated, as discussed in Articles 90 and 138. Allow this shellac to dry well.

Push as many core laminations into the coil-form hole as can be forced in, evenly extending at both ends about 3 in. Now, bend the iron strips, one at a time from each end, around the coil form, so they lap about 1 in. Cut off any that are too long. This will complete the transformer core, so it will carry all the flux through the coils (see Fig. 113).

Mount the finished transformer so its overlapped core section is wedged down out of sight, in a slot in the wood base. Binding posts of some sort should be put on the ends of the base, and the primary and secondary leads fastened under them. Figure 113 shows these details in the small sketch.

Caution! Never connect this transformer any other way but as follows:

> **Primary — 2,200 turns, No. 30 — to 110-v. a.c. source.**
> **Secondary — 150 turns, No. 20 — to low voltage use.**

The reverse connection is extremely dangerous! So, mark the primary and secondary terminals plainly.

Use a regular two-conductor, 110-v. lead and plug to connect the primary terminals to the 110-v. a.c. source of power. Any

kind of insulated wire may be used to connect the low-voltage terminals to their load.

This transformer operates on a.c., and gives out a.c. It is a step-down transformer because it lowers the voltage from 110 down to about 7. What ratio is this transformer? How many times will it raise the current? (Refer to Art. 139.)

This transformer will operate most doorbell circuits, "call-bell" circuits, and small toy motors. It will nicely operate the model series (universal) motor made in Experiment 38. Try it. **But never "short" transformer coils, because this would ruin the** coils (burn them out, probably). Do not operate the transformer too long if the core gets very hot.

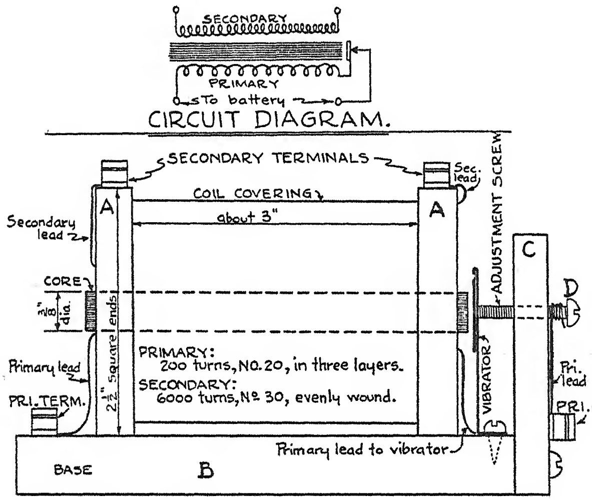


FIG. 114. Spark-coil details.

Experiment 50. Making a small spark coil or shocking coil. Materials needed: some "stove-pipe" wire (soft iron) for the core; wood for the coil ends and base; 4 binding posts of some kind; No. 20 double-cotton-covered wire for the primary; No. 30 enameled wire for the secondary coil; some sheet iron (tin can) for the vibrator; a contact screw.

First, cut two wooden end pieces, A, about 2½ in. square, as shown in Figure 114. Drill or cut in the middle of each of these end pieces a ⅜-in. diameter hole for the core.

The core is next to be made. Cut even lengths of straight iron wire, and form in a tight bundle that will fit snugly into the holes in the coil ends, as shown. This iron wire laminated core should extend beyond each end block about ⅛ in. Be careful to use long enough wires in the core, so the end blocks will be about 3 in. apart inside the coil.

Tape the iron core well between the end blocks. If you have no tape, then just use several layers of heavy brown paper. The windings may now be put on the core thus made.

The **primary** should be wound on first, nearest the iron core, in this type of transformer. (The low-voltage winding is usually put on nearest the core, for reasons of insulation.) **The primary winding should be 200 turns,** No. 20 double-cotton-covered wire, in three evenly wound layers. Bring out the ends of this winding through small holes in the end blocks, as shown in Figure 114; leave about 5-in. long leads for later connection to the terminals and vibrator.

Now cover the primary winding with tape or heavy brown paper. Be sure there is no "crack" or crevice at either end, at the coil ends. The two windings **must** be kept apart, for most satisfactory results.

Then the **secondary** may be wound on, with 6,000 **turns** of No. 30 enameled wire, in even, smooth layers. It helps to keep neat layers to cover each one with a sheet of wax paper before starting the next layer of turns. Wind all coils like thread is wound on a spool — evenly, back and forth, in layers.

Between each 1,000 turns, wind on two layers of heavy paper — wax paper from cracker boxes is good insulation for this job.

This completes the "transformer" itself, but it must now be mounted on a suitable base, and an interrupter added to break up the d.c. to the primary coil.

File the core wires even at both ends of the coil. A little glue or shellac painted on the core ends will help to keep each separate wire in place.

Arrange an interrupter (vibrator) with a tin (iron) armature and a long brass machine bolt for adjustment. The hole in the wood piece, *C*, must be tight enough on the bolt, *D*, that the adjustment will stay at that point, when once made.

Mount two primary and two secondary terminals as shown. Make the necessary connections to these from the coils. Follow

the wiring diagram given in Figure 114, for details of the vibrator (interrupter) and its connections. It is exactly the same as the wiring used on a vibrating doorbell.

Adjust the vibrator so it just touches the bolt, *D*, when no current is in the primary coil. Then connect two No. 6 dry cells in series to the primary terminals. The vibrator should buzz evenly, without much sparking at the contacts. For short intervals, this coil can be operated on the step-down transformer made in Experiment 49.

Touch your fingers lightly to the secondary terminals; a mild shock will be felt if the coil is properly operating. If 9,000 or 10,000 turns are wound on the secondary, enough voltage will be produced to jump a small air gap. By adjusting *D*, the frequency of the high voltage may be varied.

141. "Step-Up" Transformers. This type of transformer is known by several of its characteristics, as follows:

Secondary voltage is **greater** than **primary** voltage.
Secondary turns are **greater** than **primary** turns.
Primary current is **greater** than **secondary** current.
Primary wire size is **larger** than **secondary** wire size.

Check each of these statements with what already has been said about transformers. Are they logical?

142. "Step-Down" Transformers. This type of transformer also has certain characteristics, namely:

Primary voltage is **greater** than **secondary** voltage.
Primary turns are **greater** than **secondary** turns.
Secondary current is **greater** than **primary** current.
Secondary wire size is **larger** than **primary** wire size.

Check these items with other transformer data. Compare this step-down type to the step-up type.

Make up some kind of a comparison table for these two main types of transformers for your notebook.

SUMMARY

Alternating current comes in evenly spaced **waves**, and alternates its flow direction in the circuit. (D.C. does not reverse.)
A **cycle** is one complete wave form of **two alternations**.
An **alternation** is a single pulsation of an alternating current.
Frequency = **cycles per second.**
Alternators are simply a.c. generators.

Speed of the alternator directly affects the generated frequency.
A.C. is related to d.c. by these facts:

Maximum a.c. = (1.41)(d.c. of an equal power)

D.C. value = (.707)(Maximum a.c. of an equal power)

Electroplating by a.c. is impossible.

Transformers produce a.c.; can be operated on a.c. only, unless d.c. to primary is vibrator-interrupted, in some way.

Transformers are very efficient; with their assistance we can use a.c. in hundreds of voltage and current values without the severe losses that such a d.c. system would demand.

Transformer parts:

Primary coil — on input side; must be completely insulated.

Secondary coil — on output side; must be completely insulated.

Core of laminated iron, to carry flux through both coils.

Transformer power (at 100 per cent efficiency);

Primary watts = secondary watts.

$$\frac{\text{Pri. turns}}{\text{Sec. turns}} = \frac{\text{pri. volts}}{\text{sec. volts}} = \frac{\text{sec. amps.}}{\text{pri. amps.}} = \text{ratio.}$$

Step-up transformers raise voltage and lower current.

Step-down transformers lower voltage and raise current.

PROBLEMS

Prob. 1. Explain by curves, or a graph, the difference between d.c. and a.c.

Prob. 2. On a 60-cycle line, find the alternations in 20 seconds.

Prob. 3. Find the frequency when 640 cycles occur in 8 seconds.

Prob. 4. Find the frequency when 4,500 alternations occur in 1.5 minutes.

Prob. 5. *KDKA* has a frequency of "980,000 cycles." Find the cycles this station transmits in 2 minutes.

Prob. 6. Half the frequency will give twice the wave length of a radio station. Find the frequency of a station having half the wave length of *KDKA*.

Prob. 7. If an alternator has 30 pairs of (*N–S*) poles around the field, find the frequency at a speed of 2 revolutions per second.

Prob. 8. What effect on the frequency of an alternator will increasing its revolutions per second three times have? Why?

Prob. 9. Why must power-station alternators run at the same speed, regardless of their load? Explain.

Prob. 10. Why does the alternator need no commutator? What effect on the machine would adding a commutator have? Why?

Prob. 11. To lower the generated voltage of an alternator, without changing the frequency, what must be done? How?

Prob. 12. Find the maximum voltage on an a.c. line of 600 volts.

Prob. 13. Find the average current (d.c. value) of an a.c. circuit known to have a maximum of 75 amperes.

Prob. 14. Find the maximum current in an a.c. circuit of 35.4 amperes.

Prob. 15. How many times per second will the peak (maximum) in Problem 14 occur when the frequency of the line is 25?

Prob. 16. Can pure hydrogen and oxygen be obtained from pure water by electrolysis, using a.c. instead of d.c.? Why?

Prob. 17. Why does an a.c. electromagnet "hum"? How does the pitch of the hum compare to the frequency of the line?

Prob. 18. Why is a rheostat, to cut down power, very inefficient? Can d.c. be raised in any practical way to higher voltage or current? Can a.c. be raised? How?

Prob. 19. Why does a battery always generate d.c.? Can a transformer be used, then, on a battery? Why?

Prob. 20. Outline a good test to determine whether a line is a.c. or d.c.

Prob. 21. Why do neon lamps flicker, on a 60-cycle line, when a hot-filament type (Mazda) lamp does not flicker?

Prob. 22. Why is the core of a transformer laminated? Explain.

Prob. 23. If a 5,000-watt transformer operates on an 11,000-volt line, find its primary current.

Prob. 24. Find the power (watts) in a 2,200-volt line carrying 150 amperes.

Prob. 25. How much current flows in a 440-volt stove that consumes 3,500 watts?

Prob. 26. Find the voltage needed to deliver 625 watts when the current must be 15.8 amperes.

Prob. 27. Find the drop in a line that has 8.5 ohms at 165 amperes.

Prob. 28. Find the watts delivered in Problem 27 line at 110 volts. Could such a line be really operated? Why?

Prob. 29. If the power in Problem 28 is delivered at 11,000 volts, find the current in the line (8.5 ohms) and the "line drop."

Prob. 30. Why is the higher voltage line more economical to operate? Would the line construction have to be changed? Why?

Prob. 31. What kind of transformer is near your house, on a pole? What is its purpose? If it steps down the line voltage 10 to 1, find the line voltage when your house voltage is 115.

Prob. 32. Find the resistance of a transformer primary coil, wound with 750 ft. of No. 24 cotton-covered copper wire.

Prob. 33. Find the transformer "ratio" when it steps up the voltage from 1.5 to 600 volts. Will the current be stepped up or down, and how many times?

Prob. 34. If the primary current in Problem 33 transformer is 65 amperes, find the secondary current.

Prob. 35. If the wire in the primary of Problem 33 transformer has an area of 33,100 circular mils, find the minimum area of the wire needed for the secondary. What wire size would probably be used?

Prob. 36. If a transformer was only 95 per cent efficient, find its output in watts, if the input is 45 amperes at 650 volts.

Prob. 37. How much energy, in watts, is lost in Problem 36 transformer from all causes? (Mostly from eddy currents and heat.)

Prob. 38. Find the primary turns needed to step 110 volts up to 660 volts, if the secondary winding has 1,200 turns.

Prob. 39. When the primary has 500 turns, and the secondary has 3,000 turns, find the secondary current if the primary current is 4.2 amperes.

Prob. 40. If half of the primary turns of a transformer "short out," what will be the new secondary voltage if the old secondary voltage was 400 and the primary voltage is 120?

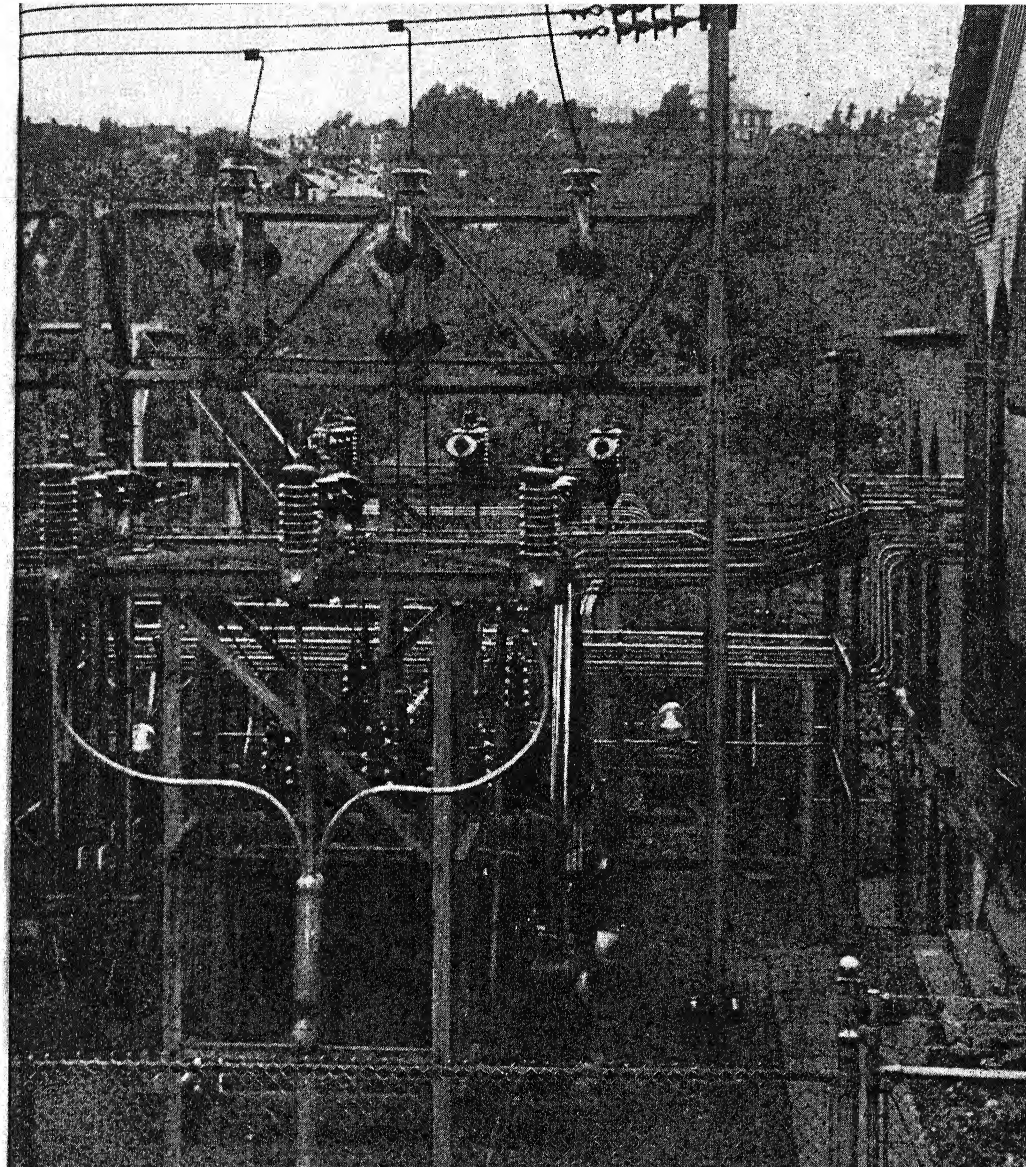
Prob. 41. Why is the secondary of a "step-up" transformer wound with smaller wire than the primary coil?

Prob. 42. At 25,000 volts per inch of air gap, find the voltage needed to jump a ¼-in. gap. What ratio will the transformer need to have, if the primary voltage is 6.25?

Prob. 43. Suppose a step-down transformer (110 v. to 7 v.) is accidentally connected with the low-voltage side on the 110-v. a.c. line. Find the output voltage in this case. In this light, can a "toy transformer" become dangerous? How?

Prob. 44. Why has the invention of the transformer revolutionized electric power?

Prob. 45. Why is it cheaper to use a doorbell transformer than to use dry cells to operate a bell? The transformer operates all the time, too.



FROM TRANSMISSION TO DISTRIBUTION VOLTAGE

Transformer stations are necessary to step down the 66,000-volt power from the distant generating station to 11,000 for distribution to district stations. These in turn step down the voltage to 2200 or 4000 volts for distribution to neighborhood transformer primaries.

Such stations are largely automatic, with special relay protection against all kinds of station faults, line trouble, and load difficulties.

Chapter IX

DISTRIBUTION SYSTEMS: DELIVERING ELECTRONS

EVERYBODY agrees, in this modern world whose byword is "efficiency," that a central power station is the best, where possible. The individual power plant is obsolete now. However, the central power plant would never have come into use, if electrons had not been discovered and put to work. Just imagine a modern town with a central power plant that delivered its power to all the customers by steampipes, belts, rope drives, and such! Central power stations were built only after electricity was put to use as a "power deliverer," for the general distribution of energy to distant places for use there.

144. The Central Power Plant. There are several reasons why the modern city has a **central** power plant, instead of hundreds of small "individual" plants. First of all, it is far more economical of fuel to burn coal in a large, well-equipped central powerhouse, than to burn it in the simple, poorly equipped, small, individual plants. The large plant can install coal crushers, superheat boilers, ash conveyors, etc., to give the best service and greatest energy for the money spent.

Fuel, bought in trainloads and delivered directly to the huge coal bins of the central station, will cost less per ton, of course, than when purchased in ton lots and hand shoveled into small boilers.

Water power, on a small scale, costs much more per *KWH* (kilowatt-hour) than when built in great dams as at Boulder or at Niagara Falls.

Wages for a large, central powerhouse force will not be much more than the wages of the crew for a small plant, at some obscure place. In larger plants, the working conditions are usually better than in smaller, poorer-equipped plants.

Allowing for a nominal profit, the large central station with its modern equipment can supply power at a lower cost per *KWH* to the customer, including the losses in the transmission line, than can the individual small plant operated for only a few customers.

145. The Customer's Varying Needs. Most homes as well as stores, factories, and manufacturing plants keep a routine "schedule" of things to be done. Most homes usually are electrically lighted from about 6 o'clock in the evening to 11 o'clock. The radio is "on" at the same hours. The greater number of stores are open from 9 to 6 o'clock, and their "loads" are nearly the same from day to day, and so on.

Large power companies keep accurate records that show exactly how much power is sent to the lines at every minute of the day and night. These records, interpreted in general terms of what the people of the city do at certain times show the following:

Monday — "washday" — heavy load, 8:00 A.M. to 12:00 Noon.

Tuesday — "ironing day" — heavy load, 10:30 A.M. to 3:00 P.M.

Saturday — "shopping day" — heavy store and railway load.

Noon, everyday — "rush hour" — heavy railway load.

Five o'clock — "rush hour" — heavy railway load.

Very warm evenings — light loads from home sections.

Very dark, cold evenings — heavy home loads.

Can you see reasons why these things are so? Think of your own neighborhood in these respects.

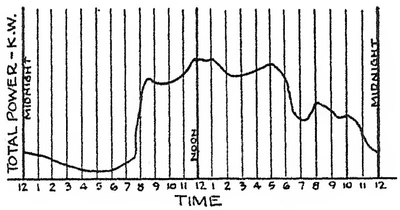


FIG. 117. Typical "load chart," showing peaks.

146. Peak Loads. These **peak loads**, as they are called, come at regular times, upon which a power company can depend and

be prepared. Power companies keep records of their daily loads on "load charts," automatically drawn by recording meters that have ink pens attached to the meter pointers. A moving paper strip thus has a line drawn on it by the meter hand, in a permanent record of the load at every minute of the day. The chart shown in Figure 117 is a sample of such a load record for an average town on a business day. Examine this chart carefully. Try to see why the peaks are located at their certain points. How would the load chart look for a small country town with no large factories?

147. Two-Wire Systems. At least two wires are needed in any electrical circuit, either d.c. or a.c. The two conductors in a railway power system are the copper trolley wire and the steel rails. Whatever power arrives in one conductor must return in the other conductor, if the circuit has no leaks, shorts, or grounds. Of course, the conductors must be insulated from each other in some way.

The usual doorbell circuit, for example, is a two-wire system. Most houses are wired in a two-wire system. Automobiles are usually wired in "two-wire" systems, if we count the frame of the car as one of the two conductors. For later comparison of the two-wire and three-wire circuits, examine Figure 118, which shows two 2-wire power systems, on two separate power sources.

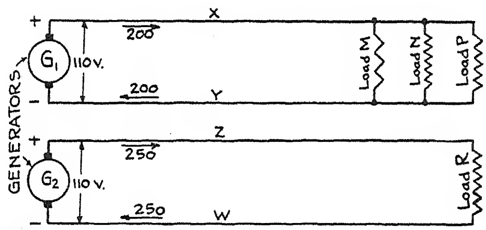


FIG. 118. Two 2-wire power systems, on separate sources.

148. Three-Wire Systems. Such groups of two-wire circuits can be operated by a method that conserves wire, which is an ingenious scheme developed by Thomas Edison to cut down the cost of his first power distribution system in New York City. The method he used allows us to replace the four wires of Figure 118 (X, Y, Z, W) with only three wires, as shown in

Figure 119. Thus, by using the so-called "Edison" three-wire system, a power company can save 25 per cent of all its wire and insulators, and still get the same results. Such a saving is not to be overlooked.

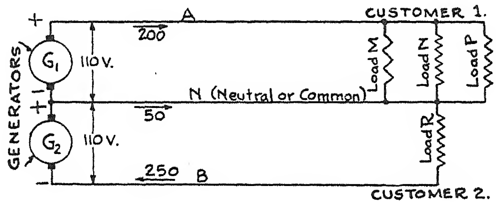


FIG. 119. Edison three-wire system.

Here, customer 1 gets 200 amperes, and customer 2 gets 250 amperes. The difference between the two currents (250 and 200) in the N or common line, is 50 amperes, flowing toward the load. So, it is clear that the

Current in the common (N) line = the unbalanced load.

If both customers got 250 amperes, then the N-line current would be zero. This would then be a balanced-load condition. To be balanced, what load would customer 2 have to draw, if customer 1 gets 563 amperes? Answer — 563 amperes. But, if customer 2 gets 300 amperes, while customer 1 draws 461 amperes, then the current in the common N line will be 461 — 300 or 161 amperes.

Notice that there are three voltages in this system:

between A and N, the voltage is 110 v. (Figure 119),
between B and N, the voltage is 110 v., but
between A and B, the voltage is 220 v.

149. Three-Phase Systems. Up to this point, this text has mentioned only "single-phase" a.c. circuits, which may be complicated enough for the beginner. There are, however, in common use in the modern industrial and commercial worlds, two-phase and three-phase circuits.

The greatest advantage of a three-phase power line over a single-phase line is that with only **three** wires, three separate power circuits may be served at once. Ordinarily six wires would be needed in three two-wire units, so the use of the new three-

phase system cuts down the cost of a line of this type to 50 per cent. This saving is quite large where long lines are built. The rapidly increasing use of three-phase power systems has done much to lower the cost of and to make more efficient electric power. Look up more information on three-phase circuits.

150. Distribution Transformers. Along our streets and highways run pole lines carrying either 1100-volts, 2200-volts, or 4000-volts a.c. These high voltages make it possible to efficiently operate the power system. At 1100 volts the "line losses" are only 1/10 as much as at 110 volts. At 2200 volts, the line losses are only 1/20 as much, and with 4000 volts only about 1/37 as much as at 110 volts.

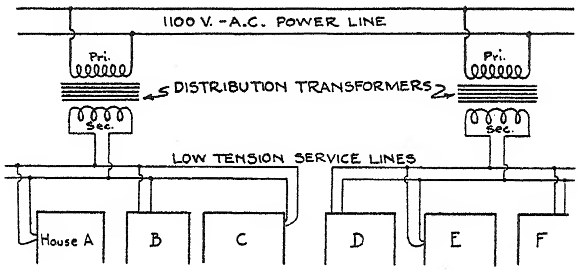


Fig. 120. A typical distribution system.

But the customer usually wants only 110 volts at his home or store. So small pole-type transformers are used to step down from 1100 v., 2200 v., or 4000 v. to the desired 110-v. a.c. secondary voltage.

These step-down transformers are commonly called **distribution transformers,** because they are used on power distribution systems. They are usually located on poles, and are always used in heavy steel cases, filled with oil to prevent leakage of current and to ventilate (cool) the windings.

A distribution system, as the name implies, "distributes" power to the various customers. A typical distribution system is shown in Figure 120.

All transformers, regardless of type, are rated in **watts** capacity or in **kilowatts.** Distribution transformers are usually of a relatively small size — from 5 *KW* to 15 *KW*. Step-down

distribution transformers in stores, large hotels, etc., are of suitable capacity to handle the "load" without overheating.

The primary circuit of a distribution transformer always has some power in it, even when **no current is drawn** from the secondary coil. This minimum current is sometimes called the **magnetizing current**, but it is so small that it is not a great loss. The same thing is true when a doorbell transformer is used on an a.c. line. There, the primary current flows all the time, but it is of such a small value, when the secondary current is **zero**, that the cost of this magnetizing power is quite negligible. Ordinarily, a doorbell transformer will not move the electric meter, unless the secondary is actually delivering current to the bell circuit. To restate all this: In any transformer circuit,

Primary current is nearly zero when secondary current is zero.

151. Modern Street Lighting. Recent trends in city street lighting are a long stride ahead of the common practice some 10 or 15 years ago. Our towns are ablaze at night with steady white light. High-speed cars and swift traffic demand such new lighting service for our roadways and highways.

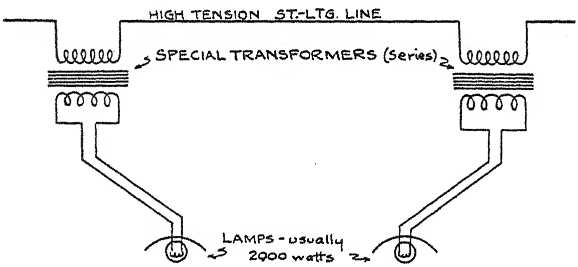


FIG. 121. Typical lamp circuit for street lights.

Until quite recently, most electric street lights were of the carbon-arc type, where both electrodes were hard carbon rods. Every city boy remembers "standing by," while the repairman cleaned the glass lamp globe and renewed the carbons on a street light in the neighborhood; these carbons were "valuable possessions" to many a boy, for use in homemade batteries, etc.

But now, the arc lights used for street lighting are better made, and require much less care than the old ones did. The new lamps operate much better than the older types. Electro-magnets automatically adjust the carbon rods so the arc is just right for the best light. The new carbons are very hard, and recently have been replaced by a material called "magnetite carbon," which gives a white steady light from the arc.

The very latest type of street lighting is a return to high-power electric lamps. These are generally operated in series to permit the use of small wire for conductors. As a rule, the circuit has small transformers, one on each pole where a lamp is to be used, connected as in Figure 121. If one lamp in such a series burns out, current can still flow through the primary of this lamp's transformer and on to the other lamps that are yet in operating condition. Is this any advantage?

Look at the electric street lights in your neighborhood; notice their location and connection.

152. Emergency Services. Such buildings as hospitals, theaters, large churches, and public halls, where many people gather at night, must have emergency service to supply light and power to stair lights, operating rooms, elevators, etc., in an emergency.

With only one service connection to a hospital, for example, grave danger would exist. In case this one line failed, the entire lighting system would be cut off, endangering lives in numerous ways. So, to care for such emergencies, separate power and lighting services are always installed in such buildings.

Automatic main switches are used to "cut over" to the emergency power source, in case the main-line service fails. Most hospitals have large "banks" of lead storage batteries, kept charged all the time, from which power and light can be drawn for six or eight hours, in an emergency, to supply the needs of the operating rooms. The occupants of these rooms would never notice the "change-over" from main-line service to the emergency service, so quickly the automatic change-over switch operates.

The law, in most states, demands that the electrician install emergency lights at exits in theaters. These lights must always be lit for any emergency such as fire.

153. Electrification of Railroads. The most difficult part of changing a steam railroad over to an electric railroad is the task

of installing proper trolley and third-rail facilities, to transmit the power to the locomotive from a central power station. Of course, where Diesel-driven-generator plants are installed directly on the electric locomotive, the power transmission problem is solved — there simply is none! But such complete "power plants on wheels" are not very efficient, and are not yet made large enough for heavy-duty freight hauling.

If third rails are used, the problem of insulating them is no small one. Most electric railroads use about 11,000 volts on the line. In bad weather, with heavy rains, snow, and ice, the third rail will "leak" severely at such a voltage. This is just one of the problems that come up when a railroad is electrified.

On most modern electric railroads, such as in the East near Philadelphia, Washington, New York, and Boston, the trolley voltage is between 10,000 and 15,000 volts. These high voltages are necessary to keep down the "line losses" (see Art. 137, with its Example).

Many of the latest electric locomotives can outrun and out-haul most steam locomotives. Thus, unless some very radical changes come to the steam locomotive soon, the electric locomotive will, in the next twenty-five years, gradually replace it. This change will not occur suddenly, because of the enormous task of first building large power stations for such a system, and the equally huge task of building adequate third-rail systems and overhead trolley lines. Both of these will require millions of dollars, which means many years of work. In the meantime the steady old steam locomotive will have to "carry on" as it does now. (See page 180.)

SUMMARY

Central power plants are more efficient than small plants.

Transmission and distribution systems are needed to get the power from the central power plant to the customer's lines.

Distribution loads vary greatly from hour to hour.

Peak loads occur at fairly regular times on certain days, making it possible for a power company to be prepared in advance for them.

Two-wire systems are the commonest and simplest type of distribution system used. Examples: doorbell circuit; house lines.

Three-wire systems are more efficient than two-wire systems. Conductors are usually labeled *A*, *N* (or common), and *B*. Two circuits are possible in this system on single-phase power. Great saving of wire, insulators, and line losses can be had, because two circuits can be operated over three wires.

Balanced loads are loads that are exactly equal in *E* and *I*. *N*, or common line, must carry the unbalanced current.

Three-phase systems permit three wires to carry power to three circuits. This saves 50 per cent of the wire.

Distribution transformers are special step-down transformers used to lower the 1100 or 2200 volts on the distribution line to the 110 volts needed at the house. Other voltage ratios also are used.

Primary power is nearly zero when secondary power is zero.

Street lighting is usually by means of arc lights or by incandescent (Mazda) lamps.

Series circuits are usually employed.

Emergency service must be installed in theaters, halls, churches, hospitals, etc., where failure of light may cause loss or danger of life.

PROBLEMS

Prob. 1. Find the power in *KW* being transmitted in a 22,000-volt line carrying 19 amperes.

Prob. 2. What horsepower does the power in Problem 1 represent?

Prob. 3. At 1100 volts, what would the current be, in Problem 1? Why?

Prob. 4. What ratio of transformers would be necessary for raising 650 volts (generated) to 11,000 volts (on the line)?

Prob. 5. Find the resistance of an aluminum transmission line, 8 miles long, No. 0 wire.

Prob. 6. Find the "drop" in Problem 5 line, at 85-amperes load.

Prob. 7. Find the *KW* lost in Problem 5 line.

Prob. 8. At 10 times as much voltage, what losses would occur in Problem 5 line, in transmitting the same power?

Prob. 9. How will greatly increased voltage on a line affect the cost of the line? Why?

Prob. 10. Why are low voltages not usual in heavy power lines?

Prob. 11. Make a chart or graph that shows the electric load for your home on an average weekday of 24 hours.

Prob. 12. At what periods of the day will a street-railway power load have high "peaks"? Why?

Prob. 13. How will a very rainy evening affect a power company's load? Why?

Prob. 14. What effect will the addition of 65,000, 110-volt electric clocks, each drawing only .01 ampere, have on the total power used?

Prob. 15. Find the *KWH* from the clocks of Problem 14 for 24 hours.

Prob. 16. At 5½ cents per *KWH*, find the total "bill" for these clocks.

Prob. 17. How do thousands of electric curling irons, usually used during afternoon hours (3 to 4, say) affect the load curve of the power company?

Prob. 18. Does a power company have any "right to make a fair profit"? Why? Who gets paid out of this profit?

Prob. 19. Diagram a three-wire Edison system using step-up transformers and step-down transformers.

Prob. 20. Find the current in the common (N) line, when A load is 618 amperes and B load is 582 amperes.

Prob. 21. If loads A and B in Problem 20 were both 600 amperes, what "drop" would occur in a .7-ohm N line? Why?

Prob. 22. Can the usual "distribution" loads be exactly balanced? What factors make this so?

Prob. 23. Why must a power company maintain voltage on the lines 24 hours a day every day in the year? Is such a "service," even when not continuously used, an advantage to the householder? Why?

Prob. 24. For such a "service" as in Problem 23, should there be a minimum "bill"? Why?

Prob. 25. Who pays for our street lighting? Who should?

Prob. 26. What savings arise from series-connected street lights, rather than parallel-connected lights?

Prob. 27. What main advantage has a doorbell transformer over dry cells, as a source of power?

Prob. 28. What advantage has an automatic-heat electric iron over the old-type stove-heated iron?

Prob. 29. What special attentions should be given to lighting circuits in such places as hospitals and theaters? Why?

Prob. 30. How does Ohm's law "fit into the pattern" of electrification of great railroads? What special problems enter the great task of completely electrifying our railroads?

MUSIC, LIGHT, AND TIME FROM THE SAME LINE

Power for the radio, the electric clock, and the lamp comes into the home over the same wires — truly a modern miracle. Refrigeration, air conditioning, electric cooking, power for cleaning and washing and ironing, all the many comforts and conveniences are available by the use of modern electric appliances and equipment.

The electrical engineer has given us all this wealth of happier living in our homes. To his inventive genius goes the credit of putting the electron to useful work.

But without the power company, with its generating stations and far-flung networks of transmission and distribution lines, all these benefits would be practically impossible and unknown.

Chapter X

ELECTRICITY IN THE HOME: DOMESTIC ELECTRONS

ELECTRICITY has completely revolutionized the home life of the modern world. Think of all the jobs that were purely hand labor and are now performed by the aid of the electron. From the electrically pasteurized milk in electrically made bottles that stand on our doorsteps in the morning, to the electric alarm clock that we "set" just before retiring at night, our entire day consists of using electrically made or handled products.

Look at a simple wall socket in the home. Just think of what a multitude of "services" that socket can bring to the home—including such things as radio concerts, accurate time at every second, cooling breezes, warmth where needed, ice in the refrigerator, hot tea or coffee, scalding water for kitchen use, light, and power for a hundred tasks. We surely live in a world of ever new marvels, since the electron is our ally.

Following are a few examples of the many services performed by electricity in the modern home. From them, what prediction can you make about the future home, thoroughly electrified?

TABLE XXI. HOME ELECTRIC SERVICES

	Approximate Cost
Washing machine	8 cents a washing
Electric iron	3 cents an hour
Vacuum cleaner	1 cent an hour
Sun lamp	1 cent for 15 minutes
Electric refrigerator	5 cents a day
Electric clock	12 cents a month
Radio	3 cents a day
Electric toaster	1 cent for 25 slices
Electric percolator	1 cent for 20 cups
Lamp, 60-watt	1 cent for 3 hours

Of course, Table XXI is only for average cases, with electric power priced at 5.5 cents per *KWH*. But just think how much energy we can buy for one cent, when it comes to the home through the power company's service line.

155. Service Lines. To deliver these "services" to our homes and buildings, service lines are run from the distribution transformer on a near-by pole to the wiring system in the building served.

To protect these **service lines** from injury in the building, they are always enclosed in iron pipe (conduit) or in a heavy "B–X" (flexible) cable. The Underwriters' Rules, on service lines and service connections, are very strict on these details for the sake of safety. This pipe or cable must cover the service lines all the way to the electric meter, which makes it quite impossible for any customer to "tap" the line ahead of the meter, to get his power free.

Sometimes, where the building sets far back from the pole line, the service line is put underground to make a neater and cheaper job. In this case, the service wires are special lead-covered cable, drawn through an underground conduit or pipe. The street end of this pipe usually extends far up the pole, to protect the entering wires from all danger. Inside the building, the pipe completely covers the service line all the way to the electric meter.

156. The Safety Switch. The law requires that, on the customer's end of the service line, after the meter, a special enclosed switch be installed. This switch must be so arranged that, when it is in the "open" position, no current can flow in any of the building circuits, and the voltage on the building lines will be **zero.**

This switch allows a change of wiring in the building, or a change of fuses, etc., with no danger to the operator (refer to Fig. 13).

157. The Fuse Box. The law now provides that fuses in service lines must be encased in a fireproof metal box, grounded for safety to the user. The fuse box in most homes has all the fuses mounted on a large insulating block which also contains the **safety switch.** Such construction makes it cheaper and easier to install than two separate units, one for a two-blade switch and one for a fuse "block."

WHICH FUSE IS BURNT OUT?

To tell which fuse has been burnt out, simply look at all the fuses in the "box," and note the one that looks "different"— as if it were burned brown (see Fig. 14). The mica window in the usual plug-type fuse will be clear, and show the unburned (unmelted) fuse link in a good fuse.

If fuses are labeled in some way, to show which light sockets or rooms they each protect, then knowing which room is "out" in the house, shows which fuse has "blown."

CHANGING A FUSE

Before removing the burned-out fuse, and putting in a new one, several things should be done:

1. **Find out the cause of the trouble.** A fuse just does not burn out for no cause at all. When a fuse does "blow," seek the cause, whatever it may be — a shorted lead, a wet cable, a grounded iron, etc. — and **remove it from the line.** Then
2. **Open the main switch,** and leave it open until the old fuse has been replaced with a new one.
3. **Close the fuse box,** so the eyes will not accidentally be injured by any fuse blowing out.
4. **Close the main switch,** and try the circuits again. But do not use the faulty equipment that caused the trouble on the line, until repairs have been made. No use burning out another fuse just to find out what was already known — that the equipment was faulty!

THE SIZE FUSE TO USE

Often, fuses are used that are either too large or too small. Too large a fuse does not really **protect** the line or the apparatus on the line. Too small a fuse will blow out on ordinary running loads, thus causing much trouble.

Therefore, be sure to use the correct rating (amperes) of fuses in all cases. In general, fuses of a 15-ampere rating are quite suitable for household use, in the average residential district.

Anybody can learn how to safely change a fuse. Everybody should be able to do this simple thing. You should teach, or

show, your mother (or housekeeper) how to change a fuse when necessary, to take care of the times when fuses blow out when Johnny or Sam or Bill is away.

158. Lighting for a Purpose. Most of us are very careless about lighting in our homes, at work, or at school. Two equally bad extremes are possible with electric lights that are quite common. Seldom do we have too much light, which makes the eyes burn and smart. Usually we have far too little light for good reading and seeing conditions. Incorrect lighting may cause bad eyestrain, and, when kept up for a long time, results in permanent injury to the eyes. "Spare parts" for eyes are not on the market, so some precautions on good lighting are in order.

In the average home, certain rooms are used for general living during the day. These rooms — such as the kitchen, the dining room, and the living room — should have up-to-date lighting. Table XXII lists a few good suggestions or rules for judging the electric lighting conditions in the home.

TABLE XXII. GOOD ELECTRIC LIGHTING

Room	*Lamp Type*	*Use*	*Bulb*	*Watt*	*Remarks*
Kitchen	Ceiling	General	1	75	Special globe
	Side wall	Over stove or sink	1	40	With reflector
Dining room	Chandelier	Table, meals	3	25	4 ft. above table
	Side lights	Evening light	1	25	Frosted; shaded
Living room	Chandelier	Occasional	3	25	6 ft., 6 in. high
	Floor lamp	Reading, etc.	2	40	3 ft. away; shaded
	Table lamp	Reading, etc.	2	40	3 ft. away; shaded
Hall	Ceiling	General	1	25	Ceiling drop; shaded
Stairs	Table	Mirror light	2	25	3 ft. away; shaded
Cellar	Ceiling (beams)	General	2	50	Stairs; laundry, etc.
Porch	Ceiling	Porch; steps	1	40	Special globe
	Wall	Doorway	1	25	5 ft. high; shaded

In addition to this table of lamp ratings, there are certain general rules for good electric lighting in the home:

1. **All lamp bulbs should be kept out of direct vision.** Shades on the lamps will aid in cutting down the blinding glare of electric light.
2. **Bulbs should be mounted vertically,** for longest life. Otherwise the hot filament sags toward the glass walls and breaks.
3. **Shades should not rest on bulbs,** to prevent fire hazard. This especially refers to thin paper shades.
4. **Dirty bulbs should be washed** with a wet, soapy cloth. Do this only while the glass is **cold.**
5. **Discard bulbs that are loose on their brass bases.** They are a constant danger, often "shorting" the line.

Check up the lighting in your home, to make it better, if possible.

159. Heating Appliances. Many of us at times like our toast, our steaming, fragrant coffee from the percolator, or our hot chocolate in the winter at the drugstore fountain. So we are familiar with the commoner types of electric heating devices, from this "eating" angle of daily life. But did you ever examine any of these appliances? Have you ever looked at the "insides" of a curling iron or an electric iron?

There are, in general, certain requirements for a good electric heater, if it is to "stand up" well under long use:

1. **Frames must be mechanically solid and strong,** to provide good support for the heating element.
2. **A heating element must be insulated from the frame** to prevent "grounds" and "shorts" on the line.
3. **A heating element must not burn up or melt,** but it must be so made that it can stand the heat developed. Insulation used must be either **mica, porcelain,** or **asbestos.**
4. **Connections must be firm, not loose or wobbly,** to prevent burning. They must be so made that they keep relatively cool when in use.
5. **Connection plugs must be well insulated,** to avoid any shock to the user.
6. **Flexible cords to heating devices must be asbestos**

covered to prevent burning from contact with the heater parts.

The common faults that develop in our household electric heating devices are:

Electric Iron:

1. Broken heating element caused by fall. Replace.
2. Shorted heating element caused by fall or severe use. Replace.
3. Hot connection plug, or burned connection lugs, caused by loose plug clips. Remedy: tighten up the plug clips.
4. Shorted cord, usually at or in plug, caused by excess wear. Remedy: reconnect wires inside of plug, carefully.
5. Worn cord caused by rubbing. Usually a new cord is needed, to avoid further danger to the user.
6. Wet cord, causing cord short. Remedy: dry out carefully.

Toaster:

1. Broken heater ribbon caused by fall. Replace.
2. Burned-out heater caused by excess heat. Replace.
3. Also see items 3, 4, 5, and 6 under **electric iron.**

Percolator:

1. Burned-out heater caused from excess heat. No remedy.
2. Burned-out fuse caused by excess heat when tank is dry. Remedy: have fuse renewed (bottom of percolator).
3. Also see items 3, 4, 5, and 6 under **electric iron.**

Curling Iron:

Same as under 1, 2, 3, 4, 5, and 6, **electric iron.**

160. Repairs. The common repairs needed in the home on electric appliances are of two general types: repairs to burned-out or broken cords for irons, lamps, etc.; and repairs to plug connections. These repairs are easily made in good workmanlike fashion, if a few rules are followed.

1. **Repairing broken cords:** Most extension cords for electric irons, toasters, and such heating devices are wound with asbestos, as well as insulated with rubber. Other cords for lamps, etc., are usually only rubber insulated. Most extension cords are made in the two-wire type, where the

two insulated wires are finally tightly covered, in a twisted pair, with a woven braid of cotton or silk.

In any case, to repair a broken cord, or to join two cords together to make a longer one, work should be done according to the following rules, in the order given:

a) Carefully cut away the layers of insulation on the wire; use a knife that is not too sharp, or you may cut the copper wire. A scraping method usually works best in this operation.

b) Clean the wire bright, for about 1 inch. Use care not to nick the wires. Stranded wire is very easily ruined by too harsh a scraping action. Fine emery cloth does a nice job.

c) Twist the wires to be connected tightly together. Be sure all small strands that belong together are in the same joint. Be careful to avoid "shorts" from stray strands.

d) Solder the twisted joints with a regular soldering iron and solder. If "soldering paste" or "flux" (rosin, etc.) is on hand it will make a better job, but ordinary beeswax will do if no "paste" is available.

e) Replace the rubber insulation that was on the wire with rubber tape, wound tightly in place. Lap the ends over on to the old insulation, to make an airtight, watertight joint. Cover both joints individually.

f) Apply a layer of friction tape (very sticky) over both rubber-covered joints to hold them together.

g) Wind thread or fine string outside the friction tape to make a neat job of the whole joint. A little powder applied to the outside of the friction-taped joint will prevent a "sticky" joint.

2. Repairing plug connections: Two things get wrong with plugs used on iron cords or on lamp cords: the plug terminals get loose and do not fit their mates tightly; or the cord wires break off or burn off at the terminals. These faults are easily repaired.

a) First, open up the plug, if it is the enclosed type such as an iron plug, by removing the small bolts that hold the plug sections together.

b) Remove the wires from the terminal lugs by using a screw driver on the brass terminal screws. Be careful not to lose the screws.

c) With a knife or scissors, cut back the broken or burned cord to where it is still in good condition.

d) Split the cord covering only for about 2 inches. Leave the asbestos or rubber covering intact.

e) Bare the wires for the last ¾ in. Be sure all strands are brightened. Twist the strands of each wire into a tight cable. Cut off the ragged ends.

f) Fasten these twisted cable ends under their terminal-lug screws, tightly.

g) Force insulated wires down into the slots or space designed for them in the plug; use a blunt screw driver for this.

h) Close the plug, and replace the bolts. When a spring encloses the cord as it leaves the plug, of course, this spring must be put in place before the plug is reassembled.

3. **Knots in cords to prevent "pulling":** Whenever possible, a large knot should be actually tied in the two wires of a cord, after their outside braid covering has been removed. Of course, the plug must first have been slipped down over the cord. This knot should be large enough to entirely close the hole in the plug and not pull through even under strain. The knot spares the plug terminal screws and lugs from severe strain, if the cord is jerked hard.

4. **Frayed cord covering:** In less severe cases, where only a short section of the cord is injured, but **no injury as yet to the rubber-covered wires,** a wrapping of common thread or good string will prevent further fraying out of the casing mesh or covering. Of course, to make the neatest job here, you should use a color of thread that will not look bad; black usually is best, if the same color as the cord is not at hand.

Keeping cords in good condition pays. A boy who is the "chief electrician" of the home should take pride in the way he can repair the electric cords used in his home. In this way

he adds to the comforts of the home, lessens the work of the person who keeps house, and at the same time learns how to do a useful job.

In many places, a boy can net a nice profit by keeping in repair the cords and plug units of his neighbors, at about fifteen cents per job where no new material is needed.

161. Care of Motors. Many homes have several motorized devices, such as the vacuum cleaner, the electric washer, electric hair drier, electric fan, electric refrigerator, and electric mixing machine. These motors need a little care, once in a while, to keep them in the best operating condition. Therefore, the following list of points is given for the adequate care of small motors.

1. **Bearings:**
   - *a*) Oil at regular times; use oil holes or cups for oiling.
   - *b*) Do not oil too much; excess oil will only fly off.
   - *c*) Have badly worn bearings replaced in a shop.

2. **Brushes:**
   - *a*) Remove and clean, when sparking badly.
   - *b*) Scrape or sandpaper hard, shiny spots, when "squeaky."
   - *c*) Never oil brushes.
   - *d*) Be sure brush springs hold brushes firmly on commutator.

3. **Commutator:**
   - *a*) Never oil the commutator.
   - *b*) Clean only with a cloth; do not scrape or file.
   - *c*) Be sure no commutator bars are loose or wires broken.

4. **Connections:**
   - *a*) All cables or leads must be properly insulated.
   - *b*) There must be no "grounds" on the motor frame; no "shorts."

5. **General Care:**
   - *a*) Never overload any motor; use it properly.
   - *b*) Never "stall" a motor.
   - *c*) Do not operate a motor so hard it overheats.
   - *d*) Protect the motor with fuses, breaker, or starting box.

e) Do not start too often; let the motor run continuously instead of many short start-stop cycles. This will save operating cost and cut down overheating.

162. **Bell Circuits.** Most homes have a doorbell circuit, which is usually simply a series circuit of bell, push button (switch), line wires, and a power source. The action of all these parts has already been discussed on other pages of this book. But certain general troubles in bell circuits, and their remedy, are of major importance here to the "chief electrician" of the home. When trouble arises, following are a few hints on making repairs:

1. **Bell:**

   a) Clean and tighten connections at terminals.
   b) Clean and adjust vibrator contacts. (Emery cloth.)
   c) Adjust clapper arm to strike gong as desired.

2. **Button:**

   a) Clean and tighten terminal connections.
   b) Adjust contact springs; clean contacts.
   c) Dry out any water in the case.
   d) Never oil the button parts. (Why?)

3. **Wires:**

   a) Repair any breaks. Soldered joints are the most satisfactory.
   b) Tape all joints or bare wires that might short.

4. **Power supply:**

   a) Check batteries; renew when worn out.
   b) Check terminal connections; clean and tighten.

These rules will enable you to put the average bell circuit into operation again, when the faults are merely bad contacts, open circuits, or worn-out batteries. There is no need for "out-of-order" signs on doorbells of the home of a wide-awake boy.

163. **Transformer for the Doorbell.** When batteries on a doorbell circuit need renewing very often, it pays to replace them with a special **doorbell transformer**, costing about $1.

This device is a step-down transformer of 110-v. to about 8-v. a.c. It can be used only on a.c. lines, because it will not operate on d.c. lines. But most power-distributing systems to homes

are 110-v. a.c., so doorbell transformers have recently grown in use.

To successfully install a doorbell transformer, only a few simple rules need to be followed. Anyone who is careful and knows a little about a transformer can do the job well.

1. Disconnect and remove the batteries to be replaced.
2. Mount the new doorbell transformer in a firm place with screws through holes in its base.
3. Connect the primary leads (heavy wires, coming out of the transformer case) to the 110-v. a.c. lines. Be careful to first turn off the main switch.

   Caution: Be sure you have the primary leads connected to lines not in a switch circuit, but going directly to the fuse box for the house. Otherwise, the switch operation will cut off current to the primary. The primary leads must connect the transformer directly across the main line, to "hot" wires directly from the fuse box. To be sure of this, trace out both wires you intend to use, all the way to the fuse box.
4. Tightly tape the 110-v. a.c. connection joints.
5. Connect the bell circuit to the secondary terminals. (Do not short the secondary terminals.)
6. Close the main switch again.
7. Try the bell — it should ring loudly when the button is pushed.

164. The Telephone. The telephone has, in the past decade, become very common in our homes, stores, offices, etc. It surely has done much to "speed up" our modern world of business, besides being a great convenience in our social world. The United States has about three fourths of the world's telephones.

Two main parts make up any telephone: the carbon-grain transmitter (mouthpiece) and the receiver (earpiece).

The transmitter is simply a specially made variable resistor, built so it can be operated or "varied" by the voice waves of the telephone user. Two small metal plates (brass) are held about 1/16 in. apart, in a small round box, attached to the thin diaphragm of the transmitter. Between these brass plates are some very small round carbon balls, loosely held by the little box.

When current is sent through this transmitter from a battery

(or d.c. generator at the Telephone Company), the current will be varied by any vibration of the voice waves rattling the diaphragm and carbon-grain box. This is because any change in how tightly the carbon grains are packed between the brass plates will change the resistance of the transmitter and thus vary the current going through it. (Just a matter, you see, of Ohm's law: $I = E \div R$.)

The receiver is a special electromagnet, wound with many turns of fine wire, that operates a thin iron diaphragm held very near it by the rubber case and cap.

The varying current ("voice" current) from the transmitter comes over the line from the distant person to the receiver at the ear of the listener. The receiver diaphragm is vibrated by the magnets in the receiver causing sound waves in the air which can be heard if near the ear. In table form, these changes from the speaker's lips to the hearer's ears are as follows:

TABLE XXIII. ENERGY CHANGES IN A TELEPHONE SYSTEM

Energy Form	*From*	*To*
Sound waves	speaker's lips	transmitter diaphragm
Mech. vibrations	transmitter diaphragm	carbon-grain box
Elect. waves	carbon grains	line wires
Line currents	transmitting station	receiving station
Magnetic flux	receiver magnets	iron receiver diaphragm
Mech. vibrations	receiver diaphragm	surrounding air
Sound waves	air around receiver	listener's ear

Proper use and care of a telephone can all be condensed to a few pertinent points:

1. **Bell box:**
   a) Never get any water into the box.
   b) Never bang, bump, or jar the box. This may injure the ringer mechanism.

2. **Extension cord:**
   a) Keep the cord unknotted and unkinked to prevent wear.
   b) Never wet the cord.
   c) Have the cord replaced when worn or frayed.

3. **Telephone:**

   a) Never drop the telephone; its parts are fragile.
   b) Hold the telephone vertical when in use; do not tip it over.
   c) Speak in a soft, natural voice; never shout in it.
   d) Keep the earpiece and the mouthpiece hygienically clean.

165. The Modern Radio. It hardly seems possible, yet radio has grown to its present stage of development and use largely since the World War. Most homes have a radio, and automobile radios are growing in popularity rapidly. So rapid has been the growth from a crude, "homemade" stage to a highly efficient, neatly cased, "manufactured" stage, that the average person now knows relatively little about his home radio, with all its strange-looking tubes and intricate parts. Only an expert can repair the modern radio; he has become a highly skilled technician, with a very special field, similar to the telephone technician with his automatic telephone systems.

But all of us should know some of the general rules for good care and operation of a radio. With a little care, the average set should last a very long time. It really pays to buy one that is well made, even at a higher cost, and then keep it in good condition at all times.

1. **Antenna and ground connections:**

   a) These leads should be well insulated throughout to prevent leakage of the very small current.
   b) All connections should be soldered.
   c) Keep the connections at the radio set clean and tight.

2. **Tuning controls** (to "tune" the set to the desired station):

   a) Keep the knobs tight on their shafts.
   b) Never twist them too hard, if tight.
   c) Small children should not adjust a radio.

3. **Volume and tone controls:**

   a) Same as under 2 *a*, *b*, and *c*.
   b) Do not operate the radio too loudly; the speaker may be damaged.

4. **Tubes:**
   - *a*) Use only standard-make tubes. "Cheap" tubes are costly.
   - *b*) Replace faulty or old tubes at a reliable dealer.
   - *c*) Have the tubes tested by the dealer when in doubt.
   - *d*) Handle the tubes carefully.
   - *e*) Never use any other type of tube in a socket except the one called for in the set markings.

5. **On-off switch:**
   - *a*) Treat this switch carefully. It is not unbreakable.

6. **General cautions:**
   - *a*) Never replace tubes with the power on.
   - *b*) Never touch the insides of a radio with the power on. Danger of severe shock is great.
   - *c*) Do not attempt repairs. Call a radio expert. In the end, this will be cheaper.
   - *d*) Do not operate the radio during a severe local storm. Heavy line voltages can ruin the whole set.

SUMMARY

Cost of power is extremely low, even in coal regions. One "man power" of electricity will cost only ¼ cent per hour.

Service lines are lines from the street mains to the house.

Service lines are always enclosed in pipe at the house.

Safety switch and fuses are line and house protection.

Replacing fuses: first open the main (safety) switch.

Lamps should be placed according to their intended use. No direct rays should hit the eye; bulbs should be shaded.

Heating devices must be carefully handled and used. Faults and defects should promptly be remedied, to avoid any danger to the user. (Prevention is better than cure.) "Grounds," "shorts," and "opens" are the common faults.

Cords should be kept in good repair for safety reasons.

Motors should be kept in good condition for cheapest use. Never oil the brushes or the commutator. Keep the bearings oiled.

Bell circuits are usually simple-series circuits. Faults are easily

remedied at little or no cost. A transformer is the best power source for the doorbell.

A bell transformer should be connected to a "hot" line.

110-v. line connections should always be soldered and taped.

The telephone and the **radio** should be carefully used to avoid damage. Cheap **radio tubes** are no economy. Only standard makes should be used.

PROBLEMS

Prob. 1. Find the resistance of a service line (2 wires) from the pole to a house 215 ft. away; the wire is No. 6 copper.

Prob. 2. Find the "drop" in Problem 1 when the line current is 52 amperes.

Prob. 3. Find the power loss (watts) in these wires in Problem 1.

Prob. 4. Find the watts "burned" when a heater draws 18 amperes from a 110-volt line.

Prob. 5. At 5.1 cents per *KWH,* find the cost of operating the heater in Problem 4 continuously for 10 hours.

Prob. 6. Find the cost to burn a 25-watt lamp in a dark stairway continuously for 30 days, at 6 cents per *KWH.*

Prob. 7. Calculate the horsepower of a generator delivering 600 amperes at 240 volts to a power line.

Prob. 8. One generator in the Brooklyn Edison Company's powerhouse (N. Y.) delivers 107,000 horsepower. Find the kilowatt output of this single unit.

Prob. 9. How much current would Problem 8 generator deliver, at 600 volts?

Prob. 10. At 550 watts each, how many electric irons could Problem 8 machine "carry" as a load?

Prob. 11. At 90 per cent efficiency, find the necessary horsepower of the power plant to drive the huge machine of Problem 8 (90 per cent efficiency means the **output** is 90 for an **input** of 100 units of energy).

Prob. 12. Why should the safety switch always be put on the "line" side of the main fuses? Diagram and explain.

Prob. 13. What rating of fuse should be used on a 110-v. kitchen line that sometimes supplies a 660-watt iron, a 350-watt toaster, and a 75-watt light all at the same time? Find the line current first.

Prob. 14. Find the watts consumed by a 25-horsepower d.c. motor, assuming 100 per cent efficiency of the machine.

Prob. 15. Find the *KW* "input" to the motor in Problem 14, at 92 per cent efficiency.

Prob. 16. At 6 cents per *KWH,* find the cost to run a 7.5-h.p. d.c. motor for 8 hours, at full load; allow 100 per cent efficiency.

Prob. 17. At 6 cents per *KWH,* how much will it cost to operate a doorbell transformer, drawing only 1.2 watts at "no load" for a 30-day period?

Prob. 18. Find the necessary series resistance in the line to a 6-volt, .2-ampere lamp, to operate it on 115 v. as a "night lamp."

Prob. 19. Find the cost, at 6 cents per *KWH*, to operate Problem 18 lamp circuit for 6 hours at night.

Prob. 20. Find the cost, at 6 cents per *KWH*, to press trousers for 30 minutes with a 550-watt electric iron.

Prob. 21. Find the series resistance to use with a 32-volt, 6-ampere motor to properly operate it on the 110-v. house line.

Prob. 22. Calculate the watts used by the motor in Problem 21; by the resistor; and the total watts used. Does the resistor "waste" power?

Prob. 23. What ratio of transformer would be suitable to operate the Problem 21 motor on that line?

Prob. 24. Find the primary current in Problem 23, when operating.

Prob. 25. Find the total watts now used as in Problem 23, when a transformer steps down the voltage. How does this compare to the total watts used when connected as in Problem 21?

Prob. 26. Suppose a loose plug on an iron cord cuts the normal current of 5 amperes down to 4.5 amperes on a 110-volt line. Find the resistance of the joint and the watts lost there.

Prob. 27. Suppose an electric curling iron "shorts out" half of its heater unit that normally draws 1.2 amperes on a 110-volt line. How will this affect the current drawn? the watts used?

Prob. 28. Find the watts drawn on a 120-volt line by three 60-w. standard lamps (120 volts) in series.

Prob. 29. Why must both wires of an underground service line from street to house be put in one pipe? Explain carefully.

Prob. 30. How will dirty bearings in a house meter affect the meter readings?

Prob. 31. Why are the cheaper cotton-insulated heater cords not very serviceable? Are such cords an economy? Why?

Prob. 32. What is indicated when a certain fuse "blows" very frequently? Will a motor on this line affect this?

Prob. 33. Diagram a fuse box and safety switch suitable for your own house circuit. Label circuits to various rooms.

Prob. 34. Plan the best lighting arrangement for your living room. Show this as an elevation of the room, scale ¼ in. = 1 ft.

Prob. 35. Show by sketches how to install a doorbell transformer.

Prob. 36. Sketch a safe joint in a 110-v. line wire. Show the various stages in making such a joint: bare wires twisted; soldered joint; taped joint. (Use large scale.)

Prob. 37. Why is the armature of a motor always laminated?

Prob. 38. Diagram a small toy motor (mecano, series) operated on a step-down transformer on 110 v., with reversing switch.

Prob. 39. Diagram an electric train circuit (toy or real).

Prob. 40. What will opening the field circuit of a shunt motor under load do? Why?

Prob. 41. Why does frequent starting of a motor produce more heat in the armature than just running? Why does "stalling" cause excess heat?

Prob. 42. What electric devices in the average home account for the largest part of the bill? List them in order of watts consumed.

Prob. 43. What causes switch contacts to burn or "pit"?

Prob. 44. Why is a grounded washing-machine motor dangerous?

Prob. 45. Why is it dangerous to use the telephone during a severe electric storm?

TOMORROW'S WORLD AWAITS ELECTRIFICATION

Steam railroads will eventually give way to electric roads. River traffic will be electrified as have ocean-going vessels. The oil-burning Diesel engine or steam turbine offer a power source for these.

Taller buildings will bring better elevator service. Electrified moving stairs and platforms will speed up pedestrian traffic.

Electric power will supplant antiquated power sources now used in many rolling mills and manufacturing plants.

The home will be better lighted, cooled in summer, and heated in winter. Television will then be here.

Chapter XI

TESLA-COIL PROJECT

THE wide possibilities for experimental work with high-voltage high-frequency current never fails to attract the boy who likes electrophysical phenomena. The small but efficient Tesla coil described here, can be easily built unit by unit in the average electric-shop laboratory and will supply a safe source of high-frequency current.

Such projects, that are more than an end in themselves, have more than average value in a shop course aimed at developing experiment or research-mindedness — the scientific attitude with its inherent factor of a real thirst for knowledge. With the completion of these Tesla circuit units, the whole new field of experimentation with high frequency opens invitingly to the boy.

The truly advanced student should be urged to do his own thinking, even to the point of improving his own projects above

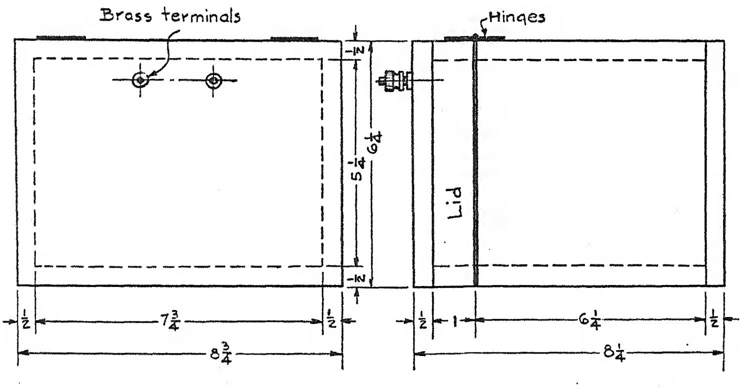


FIG. 124. Battery box for six No. 6 dry cells.

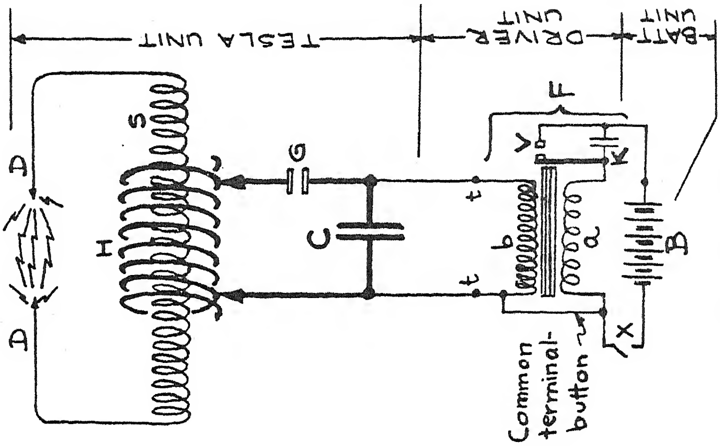


FIG. 126. Circuit.

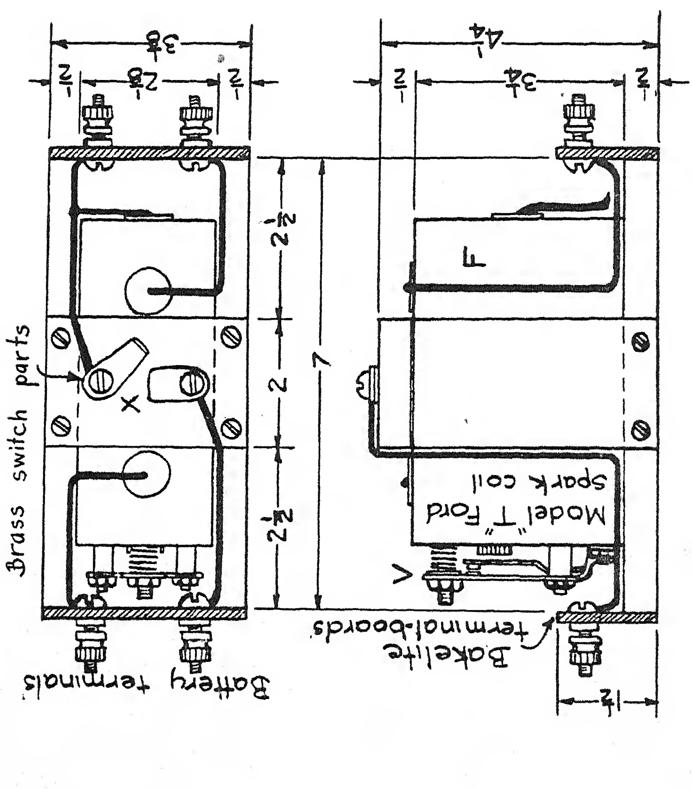


FIG. 125. Driver unit.

the detailed plans he may be using. Hence, attention is called to this note that the plans for this Tesla circuit are only the present stage of our own design. Perhaps some improvements may be incorporated by new builders which will at once lower costs and increase efficiency. The following description contains our best present design, which, if followed, will produce a satisfactory unit that will operate uniformly and fairly efficiently.

The Battery Unit. The unit in Figure 124 is not absolutely essential to the complete circuit. However, a well-built battery box, made to accommodate six No. 6 dry cells (each 2½ in. in diameter by 6½ in. over all) will certainly add to the general appearance of the job, and will make the whole outfit more readily portable.

Any wide-awake shop boy knows that the easiest way to make this battery box and lid is to make a complete box with sides, top, and bottom all in one piece. Then it may be cut in two where necessary to provide the lid and box with proper depths.

Finish: Sand and shellac the box, inside and outside. Then give it a good coat of varnish or clear lacquer.

Two brass hinges and two 10–32 by 1½-in. brass bolts with 3 nuts each for terminals, are the required hardware. Some kind of neat box latch may be used if desired.

Connections: The best way to bring the leads from the batteries to the terminals on the box lid is through the two brass hinges. This will eliminate broken leads from moving the lid. All connections may be No. 18 wire, preferably radio "push-back" wire, or rubber covered. Connect the six No. 6 cells in series, to provide a total of about 7.5 volts at the main terminals of the battery box.

The Driver Unit. When supplied with 6.5 to 7.5 volts direct current from batteries (**not** over 7.5 volts and **not** alternating current as from a transformer), the Ford-coil driver unit in Figure 125 will serve its purpose indefinitely, with no damage to its high-tension winding, its condenser, or its breaker points.

The spark coil *F* (old "Model T Ford" type) can be bought at used auto-parts dealers, for about 25 cents. Be sure the interrupter (breaker points, *V*) is intact on the coil box and that the wooden box itself has not been pried open or damaged. Reliable dealers always test coils for customers, to be sure they will deliver a good spark about ½ in. long. The box will have three

coil terminal buttons flush in its faces, as shown in Figure 125, one on the end opposite the interrupter *V*, and two on the top. The end button is a common terminal between low-tension primary coil and the high-tension secondary coil (see Fig. 126, the circuit diagram, and the Fig. 125 wiring as shown). A large paper condenser, *K*, is also in the box with the coil, and is connected as in Figure 126, to aid in a sharper "break" action at the breaker points *V*.

Clean up the coil box with fine sandpaper. File the three terminal buttons bright all over. If necessary, carefully remove nuts holding on the interrupter parts, *V*, and clean all parts bright with steel wool or fine emery cloth. If the breaker points are rough or pitted, a fine file may be used on them. Carefully replace parts on the coil-box end; make sure to have the breaker points exactly lined up when the assembly is completed.

Make a baseboard with wooden yoke clamp, to mount the coil *F* on, as shown in Figure 125. The coil must be firmly clamped down. (No nails or screws may be put into the coil box, as they would injure the coil's windings or condenser parts.)

Two terminal boards of ⅛-in. bakelite, 1½ by 3⅛ in., are screwed to the ends of the baseboard. Four brass bolts No. 10–32 by 1 in., with three nuts each, make good terminals.

Make a small switch, as shown in Figure 125 at *X*, to mount on top of the yoke. Brass strips ⅜ in. by No. 20 gauge will do nicely for the parts.

Finish: The driver unit should be smoothly sanded and shellacked, and then well varnished, to prevent leakage currents as well as to present a neat appearance. Of course, no shellac or varnish must cover the three terminal buttons, the breaker points, the terminal bolts, or switch parts.

Connections: Use heavy rubber-covered wire, such as "house wire," for the driver-unit connections. The three connections to the round terminal buttons must be soldered. Use a very hot iron, and do the soldering quickly, to prevent injury to internal parts from too much heat traveling in from the buttons. Clean off the soldered joints and varnish them, to keep them looking neat and bright and to prevent leakage.

Operation: Connect the completed driver-unit battery terminals to the battery-box terminals, for testing and adjusting the coil breaker points for best operation. Close switch *X*, on

driver-unit yoke. Adjust vibrator *V* by turning adjusting nut or thumb screw, until best (smoothest, longest) spark is obtained at the high-tension terminals. When properly adjusted, this coil should produce a spark at least ½ in. long, at a frequency of about 100 to 125 cycles per second. (The vibrator reed will then have a rough musical pitch around C an octave below middle C.) Very little sparking will occur at the breaker points when the correct adjustment is reached, and vibrator parts will not get hot or "burn."

Caution: 1. Avoid any shocks from the driver unit. It is capable of delivering about 1,000 volts, a really dangerous voltage at any frequency below 25,000 cycles per second. (Above 25,000 cycles per second, current travels only on the outside of any conductor, and so can do no harm to the body as a conductor. Below 25,000 cycles per second, current uses the whole conductor as a path, and so could injure the body if we come in contact with it at any voltage over 100.)

2. Never short-circuit the high-tension terminals of the driver unit. This would burn out the very fine wire windings in the secondary coils, and thus ruin the unit.

3. Do not use the unit on any a.c. voltage, and on no d.c. voltage above 7.5 volts. Such misuse will not produce a greater spark output, but will cause the condenser *K* to puncture and the breaker points at *V* to burn or pit.

The Tesla Unit. The most important thing about any high-frequency apparatus is the insulation of all parts. So extra care must be used on this whole unit in this matter. All insulating materials used must be clean and very dry. Several smooth coats of good shellac and varnish or clear lacquer on all wood parts, on the high-voltage secondary *S*, must be carefully applied, if the completed unit is to function well.

The following order of construction for this unit has proven the most efficient in time and energy. Figure 127 contains the important details and dimensions. Where dimensions are not shown, they may be set by the builder as the job proceeds.

Base and Condenser Case. For compactness, the glass-plate heavy-duty condenser *C* (see Fig. 126, Circuit) is housed in the box which also serves as a base for the Tesla coil itself and the terminal and spark-gap unit.

This box must be made of very dry wood, with all surfaces

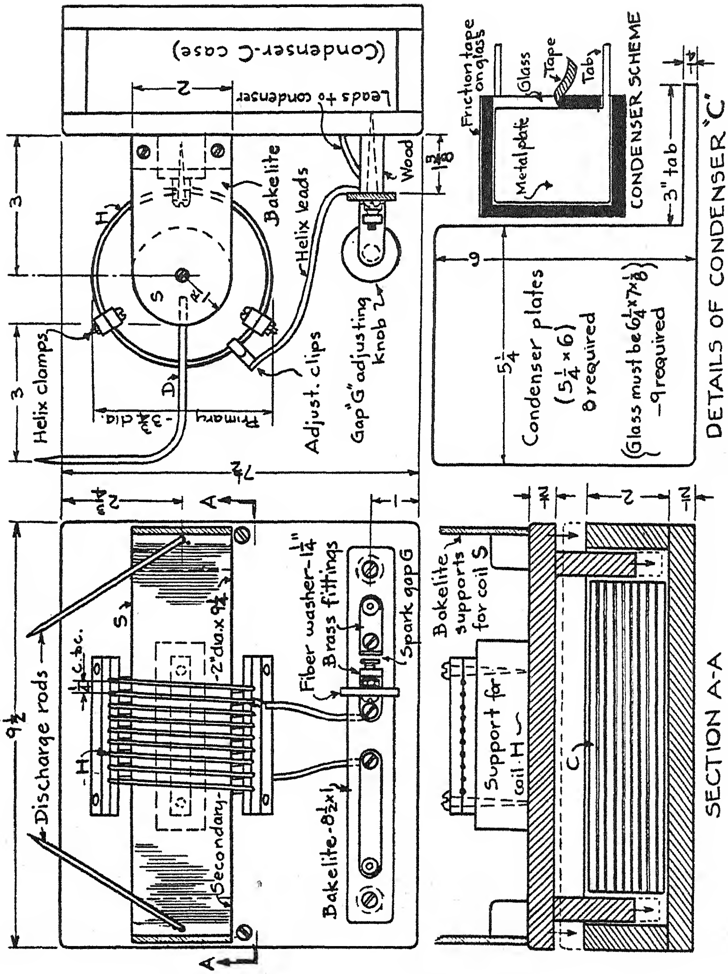


FIG. 127. Tesla unit.

inside and out well sanded, shellacked, and varnished. All box joints must be airtight, well glued. All nail heads must be countersunk, with putty applied. These precautions will cut down losses from corona discharge to exposed metal surfaces near the high-frequency secondary coil *S*.

As shown in Section A–A, Figure 127, the box lid (or baseboard proper) has two wood "runners" on it, which fit just inside the side pieces of the lower box itself. These serve to keep the box top perfectly flat, unwarped; they are crosswise to the wood grain off the top piece. This lid baseboard is held snugly down on the lower case by two screws, as shown in the plan view of Figure 127.

Secondary Coil, *S*. This is the high-tension coil of the Tesla transformer. The coil is wound on a 2-in. diameter smooth cardboard tube (mailing tube) that is 9¼ in. long. Cut the tube to exactly 9¼ in., and shellac it inside and out. Let it dry in a hot place, to drive out moisture. Careful oven drying will help.

Make two ½ in. thick wood end plugs for the tube. Shellac these well; when perfectly dry, shellac in place flush with the ends of the tube. Give the whole tube a coat of clear lacquer — and lay aside to dry thoroughly to a high luster and hard surface.

While waiting for the tube to dry, work may be done on the primary helix, *H*. When the tube is dry, wind the secondary coil on it to within ¼ in. of each end with a single layer of No. 32 d.c.c. wire — a total of about 525 turns. This job is best done by making a simple little jig to hold the coil form on small nails drilled into the center of each tube end. The coil form can then be turned by a hand-over-hand rolling motion by one boy, while another boy "feeds" on the single layer of unspaced No. 32 d.c.c. wire. This winding job is really much easier to do than it first seems. Fasten the ends of the winding under two small pins, driven into the tube 3/16 in. from each end. Then give the completed winding two coats of lacquer. Leave the lacquered coil in the winding jig to dry thoroughly.

Primary Helix, *H*. This is an air-spaced winding, 9 complete turns of No. 10 bare copper wire, held in form by three pairs of small hardwood cleats, specially made for this job.

Cut the wire 10 ft. long. Clean and polish it with steel wool or fine emery cloth. Lacquer it to keep it bright and neat.

When dry, straighten the 10-ft. length of wire out until it has no curves or kinks in it at all. Be patient on this job, if you want a neat helix unit. Then wind the straight wire unspaced on a round can or other form that is 3 to 3¼ in. in diameter. When released from its tight winding on the form, the wire will spring out close to the 4-in. diameter coil needed for the helix. A little "coaxing" will produce a coil between 3¾ and 4¼ in. in diameter, as needed for the helix.

Now make from hardwood strips, ¼ by 3/16 in., smoothly sanded, 3 pairs of clamp sticks for the helix. Carefully cut the strips to 3¼-in. lengths. Hold them in pairs and drill on the dividing cracks with a drill slightly smaller than the helix wire, for a snug fit. These holes must be spaced ¼ in. center to center. Each stick will contain half of each hole, in little half-circle grooves. Notice that two clamp pairs must have 9 wire holes, and the other pair must have 10 wire holes, to clamp all helix turns and both ends in its slots. Drill all three clamp pairs for small bolts, about No. 3–48 by ⅝ in.

Shellac and lacquer these six clamp sticks. Then put in place, as shown in Figure 127, on helix wire, spaced 120 deg. apart. When firmly in place, cut off bolt ends protruding beyond the little nuts, and soak a little lacquer down into crevices between clamp sticks. Set the complete helix aside to dry thoroughly.

Supports for *S* and *H* Coils. Make ⅛-in. bakelite end supports for the secondary coil, as shown in Figure 127. Drill for a single small flathead screw to go into each coil end, as shown. Attach small ¾ by ¾ by 2-in. blocks to these bakelite pieces, to screw them to the baseboard. Shellac and lacquer well.

Now make a suitable wood support for the helix *H*, about ¾ by 1⅛ by 4 in. Make it just high enough to bring the primary helix exactly concentric with the secondary coil when mounted as shown. Shellac and lacquer this block well.

Mount Coils *S* and *H*. Fasten all three coil supports in place on the baseboard, by flathead screws from below. The center lines of these supports must line up exactly. Then mount coils in place on their respective supports. One bakelite support will have to be temporarily removed, to facilitate mounting the primary helix with the secondary coil out of the way. Lacquer all screw heads well, to prevent leakage.

Terminal and Spark-Gap Strip. These details are shown in

Figure 127. The 1 by 8½-in. bakelite strip is held 1⅜ in. above the base on two spools or ½-in. dowel rods, drilled to suit the 2-in. screws.

Brass fittings, neatly made and lacquered, may be arranged along the bakelite strip as shown. The long brass strip shown at the left half of the bakelite strip is merely a connecting strip, to make the whole unit look more "balanced," and to bring the helix leads central with the *H* coil. The adjustable spark gap, *G*, is a very important part of the unit. One side of the gap is a fixed brass strip, about ⅜ in. wide, bent to an L shape drilled and threaded for a No. 10–32 machine screw. The adjustable electrode is a No. 10–32 by 1-in. brass bolt, with a 1¼ by ⅛-in. fiber washer as an insulating knob. A hex nut soldered on the end of the bolt forms the gap electrode needed. Examine Figure 126 which shows the circuit diagram and Figure 127 for details. **Caution**: Gap *G* must be made so that it can **never** be set closer than 1/32 in., to prevent a short circuit on the driver unit.

Leads to Helix. Two flexible rubber insulated leads run from the two center bolts on the terminal strip to the helix *H*. Small tin or brass clips are made to snap over one turn of helix wire without touching any other turn on the helix. The leads may be No. 18 stranded, single-conductor, rubber-covered lamp cord, about 5½ in. long. The adjustable contact clips at the helix must make firm contact over about 3/16 in. of the wire length, to eliminate losses.

Condenser ***C***. This heavy-duty condenser is connected directly across the driver-unit input terminals, on the Tesla unit (see circuit diagram in Fig. 126). To withstand such high voltage, this condenser must have glass plates as dielectric material.

Nine glass plates ⅛ by 6¼ by 7 in. are needed. The best material is ordinary window glass; "used" glass will do nicely. All glass surfaces must be perfectly clean and dry. Tape these glass plates at three edges with friction-tape strips cut ½ in. wide. This tape is to keep the tin plates in place between the glass plates when the condenser is assembled and to prevent leakage around the edges of the glass plates.

Cut 8 tin plates (bright tin) as shown in Figure 127 detail. Round the corners to prevent leakage at sharp points, where the electrostatic voltage is always higher than elsewhere on a conductor.

Assemble the glass and tin plates in a pile so that alternate tin tabs protrude at the left and right, 4 plate tabs each. Tape remaining exposed glass strips as the job proceeds, as shown in the condenser scheme sketch in Figure 127. Of course, glass and tin conductor plates alternate in the pile.

Wrap the plate pile in heavy brown paper, and tie up with string to keep firmly in place. This "package" must fit into the space provided for it in the condenser case under the Tesla coil. The two tab groups must protrude from the condenser unit for connection to two rubber-covered leads. Each group of tabs is connected to a 6-in. lead, and taped up firmly.

Bring these condenser leads up through small holes in the baseboard, to the same two main terminal bolts to which the driver-unit connections are made.

Screw down the baseboard onto the condenser case. Seal in place with a little lacquer around the edges, to prevent moisture and dirt getting into the condenser box. Touch up any mars with lacquer.

Discharge Rods. Make two neat, needle-pointed rods of No. 10 bare copper, lacquered and bent to shape as shown. These rods should be about 7½ in. long, bent at right angles with a 1½-in. radius about 3½ in. from the blunt end. The other ends, sharply pointed, are the discharge ends.

Drill a ⅝-in.-deep hole down into each end of the secondary coil, for these discharge rods to fit into. When in place, the rods must just touch against the small pins which fasten the ends of the No. 32 d.c.c. winding. This little scheme makes a simple flexible contact from the winding to the rods. The minimum gap between the points of these rods should be about ¾ in.

Connections: Check all wiring with the diagram in Figure 126. Set helix clips so that about 6 turns of the coil are "active." Set spark gap *G* at about 1/16 in. Connect battery box to driver unit; leave switch *X* open. Connect driver unit to the Tesla unit. Then close switch *X*. The Tesla coil should produce a spark between its discharge points about 1½ in. in length.

Adjustment. With driver-unit power off, vary the helix *H* turns (and gap *G* distance slightly) until greatest discharge distance is obtained from the Tesla secondary when power is turned on. The discharge at the secondary rods of the Tesla coil

is quite harmless to the body; it can hardly be felt at all, because very high frequency current travels entirely on the surface of any conductor.

Nikola Tesla. High-frequency transformers and phenomena are only a tiny portion of the whole field of investigation and invention by the famous electrician, Nikola Tesla. He was born in 1857, in Smiljan, Austrian Croatia, and is still living, in America. As a boy, his studies in the physics of electricity aroused his curiosity in this field, and when he went to school in Budapest, he continued work in electricity while studying languages and philosophy. He became an electrical engineer in Paris and then set out for America, there to work and study under the direction and encouragement of Thomas A. Edison.

For purposes of independent research, Tesla established his own electrical laboratories in New York City, and the resulting inventions have been distinguished for their brilliance as well as their practicability. He was the first to substitute a.c. for d.c. — by devising a simpler generator method than previously known. His principle of the rotating magnetic field is now widely used in a.c. machinery. Other inventions were along lines of arc lamps, incandescent lamps, condensers, radio apparatus, and high-frequency transformers — sometimes called Tesla coils.

Circuit Function. When switch X, Figure 126, is closed, the batteries furnish d.c. to the primary coil (a) of the driver-unit spark coil F. This primary current is immediately broken into a low-frequency pulsating current by the interrupter action of the vibrator and breaker points at V, on the end of the spark-coil core. Condenser K serves to quench the arc at the breaker points, thus effecting a cleaner, more rapid interrupter action at the points. The pulsating primary current sets up strong, pulsating magnetic flux in the iron core. This pulsating flux "cuts" the secondary winding (thousands of turns of very fine wire) causing an alternating very high voltage to be set up in this secondary winding, delivered to its terminals (t,t). This high voltage a.c. is used to drive the primary circuit of the Tesla transformer unit, next in the circuit.

The primary oscillatory circuit of the Tesla unit consists of a heavy-duty condenser C, spark gap G, and primary helix H which is adjustable in order to "tune" this series circuit. The gap G serves as an ultra-high-frequency interrupter in the circuit.

Any spark gap has a very low resistance, once an arc is established, so the air-gap distance does not materially add to the total resistance of the condenser-helix circuit.

In any oscillatory circuit, the current will be greatest when resonance is established to some even multiple of the driver frequency. By varying the active turns in helix *H*, and making slight gap adjustment at *G*, the circuit is tuned to resonance. In this resonant condition, the driver unit can keep this circuit heavily oscillating with a relatively large current, producing a relatively high frequency magnetic field around the helix *H*.

This high-frequency field "cuts" the many turns in the secondary coil *S*, inducing a very high voltage at high frequency in it. If the primary "active" turns at resonance is about 6.5, and the secondary turns on *S* is 525, the turn and voltage ratio of this Tesla step-up transformer is 6 or 7 to 525 or about 80 to 1. If we assume a 50-per-cent voltage loss in the primary circuit (from inefficient insulation) the helix voltage may safely be estimated at half the driver voltage, or about 500 volts in this design. Therefore, the secondary Tesla voltage is somewhere around 80 x 500 or 40,000 volts. Of course, the Tesla secondary current will be extremely small, because the total watts output will be somewhat less than the watts input, in any circuit. The discharge from this Tesla coil has a frequency of several million cycles per second, depending on the gap *G* characteristics.

Experiments. Listed here are a few of the many tests that can be carried out with this complete Tesla equipment. Growing out of these experiments, many ideas for further research will open up an increasingly wide field to the junior physicist.

Tests in Lighted Room. 1. Find out how the Tesla spark discharge varies in type of discharge and intensity with increasing distance between discharge points.

2. Add various-sized tinfoil balls on pointed ends of discharge rods, to test how discharge surface shape affects spark.

3. Spread discharge points beyond direct breakdown limits. Note how corona (purple "haze" or "cloud") forms around rods. Try paper tubing on rods, as prevention of corona leakage.

4. Examine corona region for evidence of breakdown of the oxygen in the air to nascent oxygen or ozone. Draw air into lungs through a straw held in corona region; note exhilarating effect of ozone.

5. Test various commonly accepted insulating materials in the Tesla gap. Test such materials as wood, glass, bakelite. Note how they dissipate the gap energy in heat at the "breakdown area."

6. Check ignition qualities of Tesla discharge on very thin, dry tissue paper, on wax paper, and on a paper strip moistened in alcohol.

Tests in Darkroom. 7. Check spark type and intensity at various gap lengths. (Adjust gap with long dry dowel rod.)

8. Examine corona leakage at various gap distances.

9. Check corona intensity with rods opened beyond maximum direct spark distance.

10. Check spark and corona discharge with other discharge surfaces such as tinfoil balls and small 1-in.-square flat areas of tin, in various relative positions.

11. Make 3-in. parallel vertical wires which can be slipped over the rod points. Examine the "ladder" discharge between these parallel vertical wires.

12. Widen the "ladder gap" to a slight V-gap shape, and test.

13. Test insulating materials in gap, for corona and breakdown.

14. Make 1-in. and 2-in. diameter loops of small wire to attach to discharge rod points. Why is corona absent inside these loops?

15. Make a 1-in. diameter by 1-in.-long tube of thin tin to hang on one discharge rod. Examine for corona effects.

16. Make a small tin star, with a hole in the center to slip over one discharge rod. Examine for corona pattern. Why do sharp edges and points carry a more intense corona?

17. Try out fine-wire patterns (such as your name in wire) hung on one rod, for the resulting corona effects. Note their beauty, and their similarity to the Northern Lights phenomena in nature.

18. Discharge one rod point to a 100-watt electric lamp held in the hand. Note "flow" of discharge, and bright color in lamp.

19. Same as test 18, except use 200-watt bulb. Compare results.

20. Make a comparison of the discharge type from each rod into the 200-watt bulb, held by the brass base.

21. Make a little "town" model, with a tiny church steeple under a cotton cloud, in which a fine wire, connected to the Tesla circuit, has been concealed. When the model "storm-and-

lightning" set is operating neatly, take a miniature closeup of it with a camera. Extremely realistic photos can be made this way, the method used for many modern movie sets.

22. Look up such experimental research as done by Seibt and by Lecher on "standing waves" and on "wave length." You can carry out similar experiments with your Tesla coil.

23. Experiment with various gas-filled tubes for their respective florescent characteristics in the electrostatic corona field around the Tesla electrodes.

24. Support 3-in.-square metal plates about 2 in. apart (slightly beyond direct sparking distance) on tall, dry, clean bottles or glasses. Connect one plate to one Tesla electrode. Test for sparks drawn off the other plate. This experiment will give some data on induction between similar circuit parts.

25. Look up data and experiments on the Oudin circuit, quite similar to this Tesla circuit. Try out your own ideas here.

More. By no means have we exhausted the field of research and experimentation in ultra-high-frequency phenomena. Any physics textbook, many books on the theory of a.c. circuits, and special books on electrical experiments will supply countless ideas and areas for further tests with the Tesla circuit. Walking in the footsteps of such great inventors as Tesla, Edison, and Alexanderson, may be just the inspiration some boy needs to set him upon the high road to success and fame himself. Who knows?

CAUTION: Any kind of spark apparatus, such as a high-tension spark coil or a Tesla circuit, sets up radio interference. Therefore, the operation of this Tesla equipment must be handled with this fact in mind. Some cities have special radio interference ordinances which may be invoked to eliminate excessive disturbances of this nature.

Chapter XII

THE FUTURE OF ELECTRICITY: ELECTRIFICATION

DO YOU ever think ahead a few years, to the days when you will be helping to do the world's work? The average boy does; he likes to plan how and where and what he will do, as a profession, when school days are over and he takes his place among people who "do things and make their mark."

Do you think you will be an electrician? Does electrical engineering appeal to you? Does a great humming generator reach "that something" inside of you that echoes the hum? Have you been in a modern radio station, and wished you were the station engineer there? Would you like to work in the fascinating electrical laboratories of great manufacturing companies, doing "front-line" work on newer electrical devices? Does the field of invention appeal to you?

Well, if any of these ideas have ever intrigued you, then this last chapter of the book has a special meaning to you. It is included to give you a chance to examine the world about you through the eyes of an electrician or an electrical engineer — your own eyes in a few years from now. Do not be alarmed to find the rest of this chapter filled with questions. They are here for you to read and attempt to answer for yourself, as you see things and know things to be. Think them over, discuss them with your friends and fellow students; argue about them a bit, if you disagree with other folks on points at stake in any case. Then, finally, you will come to some conclusions of your own about what you think, and about what you want to do. So here are the questions — plenty of them — take your time to read them; form answers carefully.

167. The World's Fuel Supply:

1. Can our fuel supplies last indefinitely? When do you think

they will expire (how soon)? Are there countries that already have fuel shortages? Where?

2. Are all places equally supplied with fuels? Why?

3. Is it possible that new fuels will be developed when we need them? (Necessity the mother of invention?)

4. Will water power ever decrease? Will it increase? Why?

5. Do we use our rivers for all their possible power?

6. Can all rivers be dammed? Does their "drop" and channel depth decide this question? How and why?

7. Are water-power dams costly projects? Why?

8. Have we in past years been wasteful of our fuel? Why?

9. Can the increased efficiency of our modern power plants give us any hope that our present fuel will last long?

10. Can Nature replace wood, coal, oil, or gas as fast as we want to burn them up for fuel? What does all this mean, then?

168. The Increasing Power Demand:

1. Are our manufacturing plants growing larger? Does our ever-increasing population cause this? Why?

2. What industries have a vast future?

3. Does our gradually increased "living speed" really mean more power demand? How?

4. How does the increasing power use affect the pay envelope of the skilled or technically trained worker?

5. How does the increasing power use affect the pay envelope of the unskilled worker?

6. Why is the average home now using electric power at an increasing rate? What devices have caused this increase?

7. Will increased electric-power demand bring lower rates?

8. Does increased mechanical and electrical power mean shorter working hours? Why?

9. How does this change in power and hours affect salaries and wage rates?

10. Does all this really mean an "industrial revolution"?

169. Water Power:

1. Can all large cities avail themselves of water power? Why?

2. Can the town you live in develop water power? Where?

3. Do dams in a river in any way impede river traffic?

4. Is Niagara "Hydro" a typical example of how water power can be developed in your own state?

5. Everything considered, is water power available to us free?

6. Are coastal states better situated for water-power plants?

7. Why has water power become common in Norway and Sweden?

8. Would a water-power station at Victoria Falls be practical? Why?

9. As fuels diminish, what will become of water power? Why? Why can the hydroelectric plant at Tacoma, Washington, furnish cheaper power now than the coal-burning plant of the Chicago Edison?

10. Is the Tennessee Valley project a practical one? Should the plant be relatively near the consumer? Can the manufacturer move his business to the power source?

170. Transmission Problems:

1. How does Ohm's law forever defeat very long lines?

2. Of course, at higher voltages, line losses are less. But can we indefinitely increase voltages? Why?

3. What factors make the cost of a transmission line great?

4. How does climate affect the insulation of a high-tension line?

5. Are overhead transmission lines especially dangerous? How?

6. Are underground transmission lines more costly than overhead lines on insulated towers? Compare various factors.

7. Who should pay the cost of building rural transmission and distribution lines out to the farmer?

8. How should those who damage transmission lines in any way be punished? Who, in reality, pays for these "faults"?

9. Does a power company have a right to make a fair profit on its service to the public? Were the government to own and operate all power companies, would graft be great or small, compared to private ownership? Is the average politician engineer enough to wisely and correctly decide power problems?

10. Would we all, in the long run, benefit by having our large power consumers near a natural power source instead of hauling fuel many hundreds of miles? Why?

171. The Theater:

1. Has the modern radio decreased or increased attendance at the theater? At the church service?

2. How has the modern theater recently changed its screen productions? Is the "talkie" successful, not needing improvement?

3. Has electric lighting changed the theater any? How?

4. Why is a high-power incandescent lamp better than an arc lamp for clear projection in a theater? Does it decrease "flicker"?

5. How has "canned music" affected the orchestra in the theater?

6. Could a great central broadcasting studio supply good music for ballrooms, parties, etc.? How would all this affect the musician?

7. How have pictures of a "musical-review" type affected the job of the chorus girl in smaller towns? Will this increase?

8. Will the theater and its movie ever replace the classroom? Can the school and theater work together? Explain how?

9. How has the power amplifier and power speaker changed or affected the theater? With better light on the screen and louder sounds, will the theater enlarge, to seat bigger crowds? How does this affect the job of the house electrician?

10. With more leisure in the future, will the theater expand its programs, to provide better, longer entertainment? Or will the home radio be the medium of good music and fascinating drama for most of us? Does broadcasting work offer any hope to those now in "screen" work? How?

172. Television:

1. When television comes, how will it affect the theater? Why?

2. How will television affect the broadcasting studio as it now is equipped only for sound?

3. Has radio already become too complicated for the average person to understand it? Will the advent of television increase this?

4. Will the field of radio still be a "hobby" for the average boy and man, when parts get costly and highly technical?

5. Does all this really mean that the number of radio experts will increase? How will television affect the necessary training and the pay?

6. Will the movies, with their elaborate scenes and trappings, be required to help out the sound studio, to present television? Why?

7. What price can the average family pay for a new radio set involving television? Is this also a problem for the manufacturer?

8. Why are broadcasting companies timid about buying apparatus for getting television started?

9. Will television, when it becomes common, tend to avert wars? How?

10. Where should the burden of cost rest for operation of radio broadcasting? In the future, these costs will rise with television. Then who should pay the costs? How?

173. **World Programs:**

1. Can the telephone, the radio, and television, when it arrives, be entirely a local affair? Does radio have any national boundaries?

2. Will this (Question 1) tend to draw nations closer? How?

3. In the U. S., how has the radio network, such as C.B.S., N.B.C., etc., affected the quality of programs? Why?

4. How can a great radio network benefit a government?

5. Have European broadcasts to America made friendlier feelings? Do these broadcasts always come in well?

6. Does the English language tend to become an "international" language? Why?

7. Why does radio tend to unify a people's thought and action? Is radio advertising increasing?

8. Should we have uncensored radio broadcast? Is "free speech" safe on the great radio chain? Why?

9. Will radio ever "die down," or will it increase? What is the future of radio? What per cent of homes now have radios?

10. Who should stand the cost of international programs? Is there any danger in such programs? Why?

174. **Electricity and the Physician:**

1. Why do hospitals demand automatic emergency service in their emergency and operating rooms?

2. Why does the surgeon usually work by brilliant electric light? Is the power company his ally, then?

3. Why have most hospitals added radio connections to rooms

of convalescents? Does all this "ease the patient's mind"?

4. The X-ray is the invention of the electrical profession. How has it become the physician's aid?

5. How has the art of electroplating aided the physician, the surgeon, and the dentist?

6. Can the X-ray help the dentist? How?

7. In severe fractures, how can the X-ray assist the doctor?

8. Does the X-ray promise any hope for cancer cases?

9. The electrical engineer has made very tiny electric lights. How are these useful to the surgeon? to the physician?

10. Can the medical profession gain by a closer contact with the electrical engineer? What future lies ahead here?

175. The Electrical Engineer:

1. Behind all our modern electrical equipment is the vast and deep research work done in our scientific laboratories. Are we constantly making machines which later cause us trouble?

2. Why do we continue doing this (No. 1)?

3. Has the engineer made life more secure or less secure? How?

4. Why must the electrical engineer be a "brainy" man?

5. Can the "slower" student aspire to engineering? (How did Edison get his training and education?) Was he brilliant?

6. Must the electrical engineer be a really dependable person? Why? Is his work a matter of serious nature?

7. Is the electrical engineer's salary in proportion to his work and preparation for his field of labor? Ask an engineer.

8. What kind of an education must an electrical engineer have? What will this cost him?

9. Does it pay a man to specialize in any particular branch of electrical engineering, such as telephone work, radio work, etc.? Why?

10. What future lies ahead for the electrical engineer? Does the engineering field fascinate you, and make you want to be in it and work in it with all your energy? What are you planning to do about it?

176. The Electrician:

1. Is the electrician as necessary as the electrical engineer? Why?

2. What kind of training must the electrician have?

3. Would you like to be an electrician? There are many kinds of such work; which branch do you prefer?

4. Does the average electrician have continuous work? Why?

5. What possibilities are there, for you, in electrical repair and replacement work? Do stores maintain such work?

6. Where, in your town, can an electrician get a job? What would the work be? What rate would he be paid?

7. Does unionization help the electrician as a skilled worker?

8. If steel houses come into common use, how will this affect electric welding and the electrician?

9. When railroads electrify, how will this affect the electrician?

10. Why must the junior tradesman be broadly as well as technically trained? Can he get apprenticeship as easily now as in former years? Where? On what basis?

177. The Technician:

1. The technician knows all about a relatively narrow field. How does this affect him if he loses his job? Why?

2. He is an expert in his own field. How does this affect his education and previous training?

3. Can he, being an expert, demand higher salaries? Why?

4. Can long experience develop as expert a technician as the school? How? (Is the job itself a real educating device?)

5. If you were to choose a particular field as an expert, what would it be? Why? What future does it present?

6. Why must the expert always keep abreast of all the new ideas, theories, and devices in his own field?

7. What happens to him if he fails to do this (No. 6)? Why?

8. Can the technician ever be just a "get-by expert"? Why must he "produce results or get out"?

9. Where, in your locality, can a boy get an electrical job that will finally advance him to an expert?

10. What traits of character should the technician have in addition to expert knowledge, to give him greatest advantages in a competitive world? Why?

178. The Student — You:

1. What field of work do you plan to enter? (Do not jump to a conclusion, later to regret your hasty choice.)

2. Why do you feel you are particularly suited for this work?

3. What is your favorite "hobby"? Does your hobby influence your choice in Nos. 1 and 2, above?

4. Do you have the time and money to prepare yourself best for your chosen work? Think about this, carefully.

5. Are you physically and mentally equal to do the work you hope to do? (You see, it is better for us to do successfully the work we can do, than to ruin ourselves trying to do a job we will never be able to do well.) Find your own work.

6. Does your present school program bring you nearer to your field? Is it too narrow? Is it in any way wasteful?

7. Do you plan further education, beyond your present course? Where? What? What will it cost?

8. Can you work in your chosen field and go to school at the same time? Many men do. How about night school?

9. Are you sure of your present choice of vocation? Perhaps you will change your mind later; then what?

10. Do your average grades in electricity warrant any change in your work? Do grades in school represent the pay envelope on the job? Could you do better work, if you tried?

APPENDIX

I. Vocabulary List; How to Use It
II. Answers to Problems

VOCABULARY LIST

NOTE: To use this vocabulary list to best advantage, set apart a section of your notebook for definitions, and keep therein only technical-term definitions that relate to electricity. For example, write your definitions thus:

> ARC: The flow of current between two electrodes; arcs may occur at switch points when opened under load.

Keep your vocabulary list according to the following rules, and add to it as you come across new words:

1. Arrange the list alphabetically.
2. Indent the margin on the left side so the word list stands out.
3. Use only standard terms; never use slang expressions.
4. Check the definitions with your book; with a dictionary.
5. Put all definitions in your own terms, so you really know what is meant.
6. Be clear; be definite; use examples, sketches, or diagrams wherever possible.
7. And above all, be neat.

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alternating current	ampere	arc
alternation	anode	armature
alternator	apparatus	attraction
ammeter	appliance	automatic

bank
battery
bell
breaker
brush
buzzer

cathode
choke
circuit
circuit breaker
circuit faults
clock
closed
commutator
compass
compound
conductor
connector
connection
constant
construct
contact
control
copperplate
copper-wire tables
corrode
corrosion
coulomb
counter e.m.f.
current
customer
cycle
cycles per second

dangerous
data
decompose
delivered power
device
diagram
distribution
drive
dry cell

eddy current
effect
effective value
electric
electrical
electrical engineer
electrician
electricity
electrification
electrode
electrolysis
electrolyte
electromagnet
electromotive force
electron
electroplate
emergency
energy
experiment

fault
field
fire hazard
flashover
flicker
flow of current
flux
foot-pound
form
formula
frequency
fuel
fuse
fuse box

galvanometer
generate
generator
granule
ground
ground connection

heating unit
high tension
high voltage
horsepower
hydrogen
hydrometer

impedance
incandescent
induce
inductance
induction
insulate
insulation
internal

"K" value
kilowatt — KW
kilowatt-hour — KWH

lag
laminate
lamination
lamp
law
lead
left-hand rule — L.H.R.
load

magnet
magnetic
magnetism
magnetize
magneto
manufacture
maximum
measure
meter
microphone
minimum
model
motor

negative
network

ohm
ohmmeter
open circuit
operate
overhead line
oxygen

parallel
peak
permanent
phase

pole
positive
power
power factor
power line
primary
principle
protect
purpose

radio
rate
ratio
reading (meter)
receiver
rectify
repair
repulsion
resistance
reverse
rheostat
right-hand rule — R.H.R.

safety
safety switch
schematic

secondary
series
service line
shelf life
shock
short circuit
shunt
simple cell
sine wave
single phase — 1 phase
slip ring
source
spark
spark coil
speed — r.p.m.; r.p.s.
starting box
static
static charge
step-down (transf.)
step-up (transf.)
switch
symbol
synchronous

technician
telephone
telephonic

terminal
test
thermostat
three phase — 3 phase
transform
transformer
transmit
transmitter
transmission line

underground
use

volt
voltage
volt ampere
voltmeter

water power
watt
watt-hour
watt-hour meter
wattmeter
weld
Wheatstone bridge
winding
work

ANSWERS

CHAPTER I

2. About 6.3 quintillion or 6.3×10^{18}
3. 50 coulombs
4. 15 amperes
5. ½; 3 times
9. 4 amps.
10. 6.5 amps.
11. 2.5 ohms
12. 10 ohms; 12 amps.; 72 v.; 48 v.
13. 2 v.; 4 ohms; 8 ohms
14. 5 amps.; 110 volts
15. 1100 volts; 5 amps.
16. 20 volts on each
17. 440 ohms; .25 amps.
18. 57.5 ohms; 3.48 amps.
19. 22 ohms; 1.45 amps.
20. .5 amps.; no
21. 15,000 ohms
22. .1 ohm
24. 12 amps.
25. 10,000 amps.
26. .05 ohms
27. .6 ohms
28. 525 ohms; .24 amps.
29. 600 amps.
30. 1250 volts; 10,750 volts
31. 12,500 volts; no
32. 125 volts
33. 10 or more
35. 35 amps.; 2880 volts
36. 2720 volts; 35 amps.
37. 3 volts
38. Far greater
39. 80,000,000 ohms
40. 100 volts

CHAPTER II

1. 11.5 amps.
2. The 3-ohm load
3. The 16-ohm load
4. 15 amps.
5. 9 or 10
6. 7 amps.
7. 25 ohms
8. About 10 amps. (load = 8 amps.)
9. 2.3 amps.; yes
10. Lamps — 10-amp. fuse; motor — 40-amp. fuse
14. 11 amps.; yes
15. None
16. Twice
19. Could also be 2 *S* poles
20. Attract –*S* pole; repel –*N* pole
21. Equal; 600-amp. turns each
22. Double flux
25. Use magnet
27. Can really is iron
35. Burns them
38. — side

CHAPTER III

1. 135 ohms
2. 1.6 ohms
3. 480 volts; no
4. 10 amps.
5. 525 ohms
6. 25,000 ohms
7. .008 amps.
8. .5 volts
9. 6.5 ohms
10. 2.5 times
11. 1.38 times as much
12. Greater resistance

13. Copper
15. .0257 ohms; .29 ohms
16. .45 ohms
17. 25.6 ohms
18. 13.3 ft.
19. About 6.5
20. Copper; .168 lb.; about ½
21. .138 ohms; 60 amps.
22. 8.3-volts drop
23. 1.15 ohms; 25 amps.
24. 480.5 ohms
25. 48-volts drop
26. 14.71 ft.; yes
27. 1.46 ft.; no
28. .011 ohms
29. .16 ohms
30. .11 ohms
31. 15 ohms; 7.3 amps.
32. 24.72 ohms; 4.45 amps.
33. 33.3 ohms; 8 amps.; 4 amps.
34. 80 ohms
35. .17 amps.; no, just red
36. Dimly; 131 volts
37. 6.5 ohms; 78 volts
38. .04 ohms; 20 ohms
39. 20.21 ohms
40. 1.67 ohms per 1,000 ft.; No. 10

CHAPTER IV

1. 4.4 inches
2. 16 units
4. 250,000,000 ohms
5. .00044 ampere
6. 16,666,667 ohms; 7,333 volts
8. .35 volts
9. 5.65 volts
11. 6 volts
12. 10 amperes
13. About half
14. About 60 volts
15. 7.2 volts
16. 100,000,000 lines per sec.
17. 300,000,000 lines
18. 10,000,000 lines
20. Cost factor
25. 90 volts
26. 15 cells
28. About 4.5 volts
29. 300 amperes
31. 450 volts
32. 2.25 amperes
34. 1.74 amperes
35. 294 volts
36. 514.5 volts
37. 2 No. 0
38. 19,150 mi. per sec.
40. 220 volts

CHAPTER V

1. .125 volts
2. .5 volts; 1.25 volts
3. 12,500,000 lines; 50,000,000 lines
4. 1/3 as much
6. 600 turns
7. Series
11. 14 volts
12. .15 ohms
13. 66.7 ohms
14. .149 ohms
15. 85 ohms
16. 16.7 amps.
17. 834 turns
18. 5.04 volts
19. 5.2 volts; .8 ohms
20. .5 ohms; 3.25 volts
21. 2350 ft.
22. .21 volts
23. 4.42 volts
26. .1 ohm
27. 118 volts
29. 16 amps.
30. 4.8 volts
31. 115.2 volts
32. 115.2 ohms; 7.68 ohms
33. 21.5 amps.
34. 113.55 volts; 6.45 volts
35. .2 volts
36. 75.6 ohms
37. 113.35 volts; 5.67 ohms
38. 3 units
39. 120.5 volts

CHAPTER VI

1. 12.5 ohms
2. .96 ohms
3. 4 ohms
4. 2.21 ohms
5. 16.6 volts; 22.1 volts
6. 7.5 ohms; 14.6 amps.
7. 16.93 ohms; 7.1 amps.
12. 1200 amps.
13. .00073 amps.
14. 1.33 ohms
15. 6.67 ohms, total; 4.67 ohm resistor
16. 1.56 amps.
17. 18 ohms
18. Increase
19. 28 volts
20. 15 ohms; 11.5 ohms
21. 4 times as great
22. 19.5 ohms
23. 6 volts
24. 7.5 amps.
25. 1.2 amps.
26. 8.7 amps.
27. 78.3 amps.
30. About 40 amps.
35. Lower readings
45. 45 amps.

CHAPTER VII

1. 2,400 ft.-lbs.
2. 1,625,000 ft.-lbs.
3. 4,643 ft.-lbs.
4. 25,200 ft.-lbs. per min.; .77 h.p.
5. 6.8 h.p.
6. 8.6 h.p.
7. .62 h.p.
8. 6.23 h.p.
9. 4,125 ft.-lbs. per min.
10. 11.6 min. "working" time
11. .204 h.p.
17. 935 watts
18. 880 watts
19. No. 1, 720 watts; No. 2, 725.7 watts
20. 31.25 ohms
21. 210.6 watts; heat
22. 3.86 amperes
23. .272 ampere
24. .7 ampere
25. 464.8 watts
26. 4647.6 watts
27. 93.3 watts
28. 1.07 h.p.
32. 187.5 kilowatts
33. 56 *KW*
34. 1.34; about 1 1/3
35. 98.96 *KW*
36. 791.7 *KWH*
37. 26 cents
38. 10 cents
39. $2.24
40. Less than 2 cents

CHAPTER VIII

2. 2400
3. 80 cycles per sec.
4. 25 cycles per sec.
5. 117,600,000
6. 1,960,000
7. 60 cycles per sec.
8. Three times
12. 846 volts
13. 53 amps.
14. 50 amps.
15. 50 per sec.
23. .45 amp.
24. 330,000 watts
25. 7.95 amps.
26. 39.5 volts
27. 1402.5 volts
28. 18,150 watts
29. 1.65 amps.; 14.03 volts
31. 1150 volts
32. 19.26 ohms
33. 1 to 400; current, 400 to 1
34. .16 ampere
35. 82.75 cir. mils; No. 30
36. 27,787.5 watts
37. 1462.5 watts
38. 200 turns
39. .7 amperes
40. 800 volts
42. 6250 volts; 1 to 1000
43. 1728 volts

CHAPTER IX

1. 418 *KW*
2. 560 h.p.
3. 380 amps.
4. 1 to 16.92
5. 7.24 ohms
6. 615 volts
7. 52.4 *KW*
8. 61.5-volts drop; .52 *KW*
14. 71.5 *KW*
15. 1,716 *KWH*
16. $94.38
20. 36 amps.
21. Zero

CHAPTER X

1. .17 ohms
2. 8.8 volts
3. 459 watts
4. 1980 watts
5. 19.8 *KWH*; $1.01
6. $1.08
7. 193 h.p.
8. 79,822 *KW*
9. About 133,000 amps.
10. About 145,000
11. About 119,000 h.p.
13. 10-amp. fuse
14. 18,650 watts
15. 20.73 *KW*
16. $2.69
17. 5 cents
18. 545 ohms
19. Less than 1 cent
20. 1.4 cents
21. 13 ohms
22. 192 *W.*; 468 *W.*; 660 *W.*
23. 3.44 to 1
24. 1.75 amps.
25. 192 *W.*; about .29 as much
26. 4.2 ohms; 85 watts
27. 2.4 amps.; 264 watts
28. 20 watts

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